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On the Vortex Theory of the Screw Propeller

H. REISSNER, *Berlin*

(Received June 21, 1937)

SUMMARY

In the vortex theory of the screw propeller the first problem consists in determining the change of inflow velocity produced by the helical vortex sheets starting from the trailing edges of the blades, whereby the distribution of vorticity is connected with the circulation along the blade and this again with the lift distribution.

This task is solved in two steps, the first giving a potential of very simple structure with required vortex discontinuities by a fictitious source distribution, the second removing these sources but leaving the discontinuities by a trigonometric expansion.

The result appears in such a form that the induced velocity at a point is partly produced by the circulation corresponding to the same circumference as in the theory for an infinite number of blades and partly created by the circulations all along the blade depending on the number of blades.

By this relation between induced velocity and circulation, thrust and torque of a screw propeller are shown to be determined by definite integrals of simple structure.

A complete set of equations of the whole problem is at last obtained by adding the well known relation between circulation on the one hand and lift coefficient and blade angle on the other hand. The next problem then consists of the treatment of this set of equations.

Three possible ways of procedure are shown, *viz:*

(1) Choose a desirable distribution of circulation, that is of lift, figure the induced velocities and by them thrust, torque, width, and angles of incidence of the blades. A numerical example of this is given.

(2) Assume width, pitch, and lift coefficient of the blades and solve the integral equation arising for the circulation. A successive approximation beginning with the circulation for an infinite number of blades is indicated.

(3) Assume torque of propeller, speed of the aeroplane, number of blades and number of revolutions and determine the blade dimensions and positions in such a way as to obtain the maximum possible thrust.

The calculus of variations then leads to a complicated set of conditions which are stated but must be left for a later discussion.

A detailed paper will appear in the Philosophical Magazine.

1. Outline of the Problem

The theory of the screw propeller is part and extension of the theory of the aerofoil.

The modern, so very successful development, is governed by the Kutta-Youkovsky conception of lift by circulation and by the Prandtl system of induced velocities produced by trailing vortex sheets connected to the change of circulation along the aerofoil.

The application of these propositions to the calculation of propeller performance brings with it the difficulties of a three dimensional theory of partly discontinuous fluid motion and of complicated integral equations.

Among the men who have successfully tackled the problem may be named Betz,[1] Prandtl,[1] Karman,[2] Troller,[2] Goldstein,[3] Lock,[4] and Kawada,[5] who have done very valuable pioneering work.

[1] A. Betz, *Schraubenpropeller mit geringstem Energieverlust*, Nachrichten der Gesellschaft der Wissenschaften zu Göttingen, 1919.

[2] Th. Troller, *Zur Wirbeltheorie der Luftschrauben*, Zeitschrift fur Angewandte Mathematik und Mechanik, 8, 1928, page 426.

[3] S. Goldstein, *On the Vortex Theory of the Screw Propeller*, Proceedings of the Royal Society, Vol. A123, No. A792, April, 1929.

[4] C. N. H. Lock, *An Application of Prandtl Theory to an Airscrew*, British Reports and Memoranda No. 1521, August, 1932.

[5] Sandi Kawada, *Induced Velocity by Helical Vortices*, Journal of the Aeronautical Sciences, Vol. 4, No. 3, January, 1936, page 86.

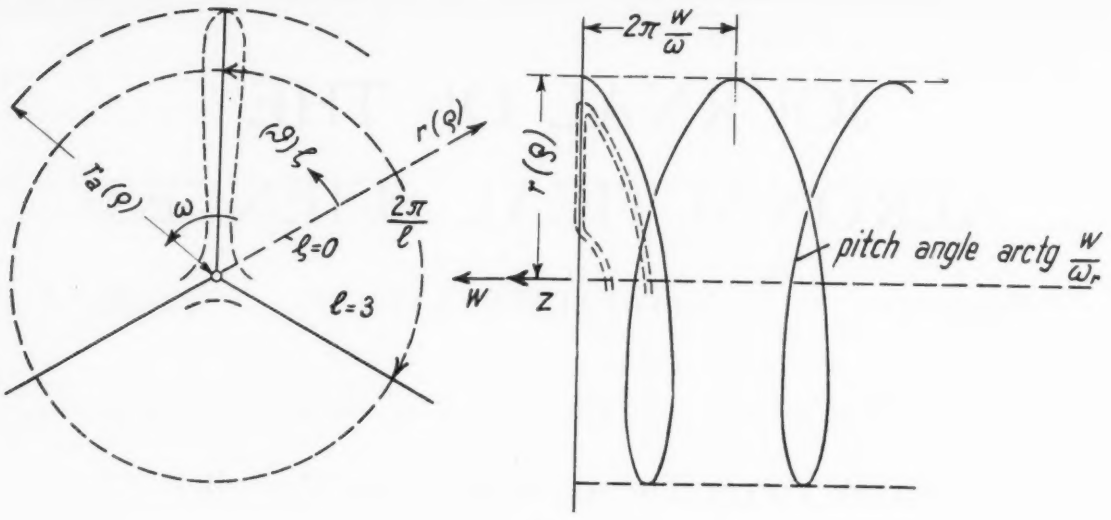


FIG. 1.

From the point to which their work has been leading the author has tried to advance further toward a rational theory which would give the interdependent relations between circulation, thrust and torque along the blades on the one hand and dimensions, angle settings, number of blades, and inflow velocity on the other.

2. First Relation between Circulation Function and Induced Velocities

According to Fig. 1, each propeller blade is represented by a bound vortex line of circulation Γ which leaves behind a helical vortex sheet. This sheet, in the first approximation, can be assumed infinitely thin and composed of helical vortex lines. The vortex strength E of this sheet is some function of the radial coordinate and connected to the circulation function Γ by the equation

$$E = \frac{d\Gamma}{dr}$$

Outside these vortex sheets the motion derives from a potential ϕ which is discontinuous at the vortex sheets in such a way that the circulation equals the step $\delta\phi = \phi_+ - \phi_-$ from one side of the vortex sheet to the other *viz:*

$$\Gamma = \delta\phi$$

To find the fluid motion produced by such discontinuities of potential, a discontinuous *fictitious source distribution* of saw-like linear arrangement along each circumference but otherwise arbitrary along the radii and giving a potential discontinuity arbitrarily prescribable along each blade center line, is assumed. Fig. (2).

Afterwards this fictitious source distribution will be removed by a trigonometric expansion in such a way

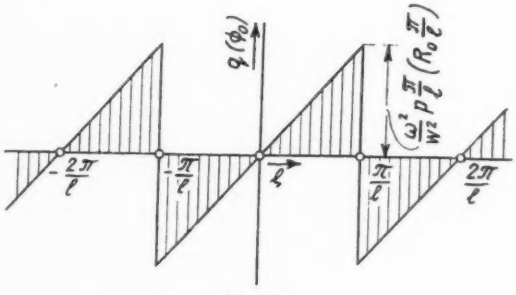


FIG. 2.

that the potential discontinuities aimed at remain unchanged.

2a. First Part of the Solution

Introducing the designations of Fig. 1 and further:
Source strength, q
Angular velocity of blades, ω
Axial velocity of blades, w

Non-dimensional radial coordinate $\rho = \frac{\omega r}{w}$, (Reciprocal advance per revolution)

Combined axial and circumferential coordinate of helical symmetry,

$$\zeta = \vartheta - \frac{\omega}{w} z$$

the differential equation of potential of helical symmetry can be written in the following form:

$$\Delta\phi \equiv \frac{\omega^2}{w^2}\left[\rho^{-1}\frac{\partial}{\partial\rho}\left(\rho\frac{\partial\phi}{\partial\rho}\right) + \left(1 + \rho^{-2}\right)\frac{\partial^2\phi}{\partial\zeta^2}\right] = -q \quad (1)$$

It is now possible to give single or two term solutions of Eq. (1) producing prescribable discontinuity distributions of potential ϕ_0 and of radial velocity $u_0 = \partial\phi_0/\partial r$ on the trailing helical sheets. Fig. (1).

First the further symbols may be chosen:

Number of blades that is of helical vortex sheets l.

The designation number k of a blade running from 1 to l.

$\zeta_k = \zeta - k\frac{2\pi}{l}$, the circumferential coordinate in each sector between two adjacent blades.

$\phi_{0,k}$ the potential and $q = p\zeta_k$ the source distribution in the same sector.

Then assuming a source distribution of saw-like shape (Fig. 2), a solution of Eq. (1) is given by[6]:

$$\phi \equiv \phi_{0,k} = \zeta_k R_0(\rho), \quad p = -\frac{\omega^2}{w^2}\rho^{-1}\frac{d}{d\rho}\left(\rho\frac{dR_0}{d\rho}\right) \tag{2}$$

Now the circulation Γ and the vortex strength E are connected to the potential discontinuity in the following way:

$$\Gamma = \delta\phi = \frac{l}{2\pi}R_0, \quad E = \frac{d\Gamma}{dr} = \frac{2\pi}{l}\frac{\omega}{w}\frac{dR_0}{d\rho} \tag{3}$$

$$p = \frac{l}{2\pi}\rho^{-1}\frac{d}{d\rho}\left(\rho\frac{d\Gamma}{d\rho}\right) \tag{2a}$$

or inverted:

$$\Gamma = \frac{\pi}{2l}\int_0^\rho \frac{d\xi}{\xi}\int_0^\xi d\psi\psi p \tag{2b}$$

2b. Second Part of the Solution

As stated above, the fictitious source distribution must now be made to disappear but nevertheless retaining the discontinuity sheets by superimposing a continuous solution of (1) arising from the trigonometrical development of the field of source density $-q$.

Putting

$$\phi \equiv \phi_1 = \sum_{n=1}^{\infty} R_n \sin(nl\zeta), \quad nl\rho \equiv \sigma_n \tag{4}$$

Eq. (1) takes the form:

$$\sigma_n^{-1}\frac{d}{d\sigma_n}\left(\sigma_n\frac{dR_n}{d\sigma_n}\right) - R_n(1 + (nl)^2\sigma_n^{-2}) = -\frac{lp}{\pi(nl)^2}\int_{-\frac{\pi}{l}}^{+\frac{\pi}{l}} \zeta\sin(nl\zeta)d\zeta = (-1)^n\frac{2p}{(nl)^3} \tag{1a}$$

This equation is solved in a well known manner by Bessel functions of imaginary argument in Watson's notation $I_{nl}(\sigma_n)$, $K_{nl}(\sigma_n)$ for shortness hereafter written

$$I_{nl}(nl\rho) \equiv I_n, \quad K_{nl}(nl\rho) \equiv K_n$$

Choosing as terminal conditions that all velocities derived from Eq. (4) disappear at infinity and remain finite at the axis, the solution using the method of variation of constants in order to comply to the source distribution p, finally can be shown to be[7]

$$R_n = -(-1)^n\frac{2}{nl}\left[K_n\int_0^\rho I_n\xi p d\xi + I_n\int_\rho^{\rho_a} K_n\xi p d\xi\right] \tag{5}$$

where one may observe that the source distribution obviously must be taken to become zero at the blade tip $\rho = \rho_a$ so that the second integral need not go further than $\rho = \rho_a$.

Combining Eqs. (5), (4), (2), and (3) the complete solution in the first sector, which repeats itself in every other sector, becomes:

$$\phi = \frac{l}{2\pi}\left[\Gamma\zeta - \sum_{n=1}^{\infty}(-1)^n\sin(nl\zeta)\frac{2}{nl}\times \left(K_n\int_0^\rho I_n d\left(\xi\frac{d\Gamma}{d\xi}\right) + I_n\int_\rho^{\rho_a} K_n d\left(\xi\frac{d\Gamma}{d\xi}\right)\right)\right] \tag{6}$$

Eq. (6) gives the potential at any place in the field as induced by the potential discontinuity sheet and degenerates into an identity on the discontinuity surface itself. To prove, as it is necessary, that the second part of the solution gives a potential ϕ traversing continuously through zero at the vortex sheets, it is sufficient to observe that the series of the second term of Eq. (6) is convergent. This will be shown in a later paragraph.

It is remarkable that the field given by Eqs. (5), (4) and (2) splits automatically into an outer and inner domain, the circle of division traveling with the circle at which the potential is to be calculated. The source strength of the inner field induces, according to Eq. (5), circulation and velocities given by the first term in a manner different from the induction given by the second term of the outer field.

3. The Induced Velocities

The velocities corresponding to the distribution Eq. (6) of the potential are obtained in the usual way as follows:

$$u^* = \frac{\partial\phi}{\partial r} = \frac{\omega}{w}\frac{\partial\phi}{\partial\rho}, \quad v^* = \frac{1}{r}\frac{\partial\phi}{\partial\delta} = \frac{\omega}{w}\frac{1}{o}\frac{\partial\phi}{\partial\zeta},$$

$$w^* = \frac{\partial\phi}{\partial z} = -\frac{\omega}{w}\frac{\partial\phi}{\partial\zeta}$$

For the purpose of this paper only the tangential and the axial velocities v^* and w^* and especially the resultant velocity c^* perpendicular to the vortex sheet at the vortex sheet itself are needed.

Considering that the half infinite vortex sheet column creates only half the velocities of the completely infinite column, Fig. 2 shows that in proportion to the undisturbed velocity $c = -w(1 + \rho^2)^{1/2}$ the induced velocity c^* assumes the value:

[6] It may be mentioned that there are other single or two term solutions $\phi_{0,k} = R_0[e^{\pm k(\zeta - \pi/l)} - 1]$ giving also required discontinuities but not as convenient as the expressions above.

[7] The general relation $K_nI_n' - I_nK_n' = 1/\sigma_n$ between the two integrals of (1a) must be taken into account.

$$\frac{c^*}{c} = \frac{-1}{2w(1+\rho^2)}(\rho w^* - v^*)$$

And at the radius $\zeta = \pi/l$, if for simplicity a dimensionless specific circulation

$$\Gamma^* = \Gamma\frac{\omega l}{w} \tag{7}$$

and a specific source density

$$p^* = \xi^{-1}\frac{d}{d\xi}\left(\xi\frac{d\Gamma^*}{d\xi}\right) \tag{2c}$$

is introduced, then:

$$\frac{c^*}{c} = \frac{1}{4\pi\rho}\Big[\Gamma^* - 2\sum_{n=1}^{\infty} K_n\int_0^{\rho} I_n d\left(\xi\frac{d\Gamma^*}{d\xi}\right) + I_n\int_{\rho}^{\rho_a} K_n d\left(\xi\frac{d\Gamma^*}{d\xi}\right)\Big] \tag{8}$$

3a. Simplification of the Velocity Circulation Relation by Nicholsons'[8] Asymptotic Approximations

For a numerical evaluation and for the discussion of convergence of Eq. (8) it is useful to introduce certain asymptotic expressions of the Bessel functions appearing in Eq. (8).

Using $\tau = (1+\rho^2)^{1/2}$ instead of ρ the asymptotic expressions due to Nicholson can be written as follows:

$$\left.\begin{aligned} I_n \equiv I_{nl}(nl\rho) &= \frac{1}{(2nl\pi)^{1/2}}\frac{1}{\tau^{1/2}}\left[e^{\tau}\left(\frac{\tau-1}{\tau+1}\right)^{1/2}\right]^{nl} \\ K_n \equiv K_{nl}(nl\rho) &= \left(\frac{\pi}{2nl}\right)^{1/2}\frac{1}{\tau^{1/2}}\left[e^{\tau}\left(\frac{\tau-1}{\tau+1}\right)^{1/2}\right]^{-nl} \end{aligned}\right\} \tag{9}$$

which are sufficiently exact for an argument of $nl\rho > 4$, which, for instance, for 3 blades and a radial abscissa $\rho = 2$ would mean $n > 1$.

Now following (2b) and putting

$$\left[e^{\tau}\left(\frac{\tau-1}{\tau+1}\right)^{1/2}\right] \equiv U_1,\quad p^*\tau^{1/2} = U_2$$

Eq. (8) changes into

$$\frac{c^*}{c} = \frac{1}{4\pi\rho}\left[\Gamma^* - \frac{1}{l\tau^{1/2}}\sum_{n=1}^{\infty}\frac{1}{n}\left(U_1^{-n}\int_0^{\tau} U_1^{n}\,d\xi U_2 + U_1^{n}\int_{\tau}^{\tau_a} U_1^{-n}d\xi U_2\right)\right] \tag{8a}$$

The first term gives the relative velocity induced at a circle ρ by the circulation at the same circle, the first series the velocities induced by the circulation at the inside of ρ and the second series the velocities induced by the circulations outside ρ.

As regards the convergence of the series terms of Eq. (8a) it is at least of the order $\sum 1/n^2$ for the following reasons. The mean value of U_2, which might be as a factor put outside the respective integral, is, if n increases, approaching its value at the limit ρ of both integrals, because with n increasing the functions U_1^{n} and U_1^{-n} are more and more concentrated at the point ρ. This results from the fact that U_1^{n} is of the type $e^{k\tau n}$ and U_1^{-n} of the type $e^{k(\tau_a-\tau)n}$. Therefore after integration and multiplication the exponential functions cancel each other and there remains only another factor $1/n$ to be multiplied with the one standing outside the parentheses in Eq. (8a).

[8] Phil. Mag., 20, 1910, page 398.

4. The Second Relation between Circulation and Induced Velocities Containing Lift Coefficient and Profile Drag

Making use of Prandtl's proposition that the laws of lift and drag of an infinite aerofoil are valid also for the element of a finite aerofoil if the induced velocities are added, and observing that for a first approximation not the value, but only the direction of the resultant velocity is changed, the following symbols and equations may be stated. Fig. (3).

Lift coefficient, $c_a = c_a' i$
Drag coefficient, c_w
Specific drag, $c_w/c_a = \beta$
Angle of incidence, $i = i_0 - \frac{c^*}{c} - \beta$
Density of air, μ
Element of lift,

$$dL = {}^1\!/_2\,\mu c^2 c_a' i\,dr = \mu c\Gamma dr \tag{9}$$

Circulation by comparison of the above expressions of dL

$$\Gamma = \frac{1}{2}\,cc_a' i = \frac{w}{2}(1+\rho^2)^{1/2}lc_a'(i_0 - \frac{c^*}{c} - \beta)$$

Specific blade width

$$l^* = lc'_a\frac{\omega}{2w}(1+\rho^2)^{1/2}$$

Using these symbols the specific circulation takes the form:

$$\Gamma^* = l^*(i_0 - \frac{c^*}{c} - \beta) \tag{10}$$

5. Thrust and Torque of the Air Screw

According to Fig. (3) and Eq. (9) the element of thrust T and of torque M can be written as follows:

$$dT = dLc^{-1}[wr - v^* - \beta(w + w^*)]$$

$$dM = rdLc^{-1}[w + w^* + \beta(\omega r - v^*)]$$

Using for the small quantities v^* and w^* the expressions (Fig. 3):

$$v^* = \frac{c^*}{c}w,\quad w^* = \frac{c^*}{c}\omega r$$

integrating further on over the l blade lengths, neglecting products of small quantities like βv^* and βw^* and

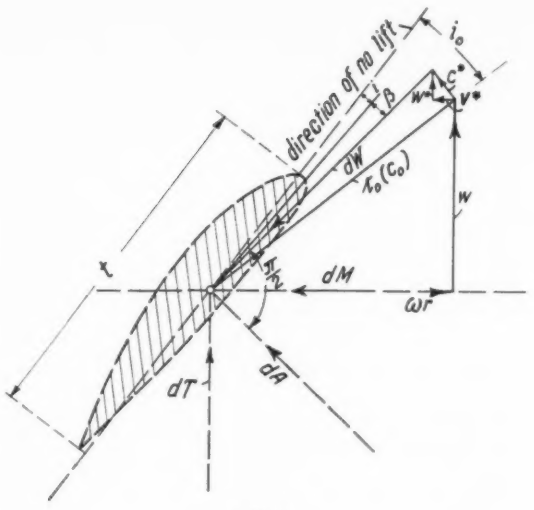


FIG. 3.

using Eq. (10), the following expressions for the thrust and the torque of the whole airscrew are developed:

$$\left.\begin{aligned} T^* &= \int_0^{\rho_a} d\rho\Gamma^*[\rho - (c^*/c + \beta)] \\ M^* &= \int^{\rho_a} \rho d\rho\Gamma^*[1 + \rho(c^*/c + \beta)] \end{aligned}\right\} \quad (11)$$

where

$$\left.\begin{aligned} T\frac{\omega^2}{\mu w^4} &= T^* \text{ the specific thrust} \\ M\frac{\omega^3}{\mu w^5} &= M^* \text{ the specific torque} \end{aligned}\right\} \quad (12)$$

and $\rho = \omega r/w$ is again the dimensionless radial coordinate (reciprocal advance per revolution) and ρ_a its value at the tip.

6. Approximate Theories

Instead of Eq. (8) some approximate propeller theories use a relation between the circulation Γ and a certain mean value c_m^* of the induced velocity which may be explained either as induced by an infinite number of blades or, as the author prefers to look at it, as the mean of the induced velocities between each pair of adjacent blades.

The relation is obtained by following a circuit around a blade section and observing that only the circumferential part behind the blade contributes to the value of the circulation.

In this way one gets the relation

$$\Gamma^* = 4\pi\rho\frac{c_m^*}{c}\left[1 + \rho\left(\frac{c_m^*}{c} + \beta\right)\right] \quad (8b)$$

which on comparison with Eq. (8) shows that the *first term in Eq. (8) gives the mean induced velocity* or the velocity for an infinite number of blades up to the first order of the small quantity c^*/c.

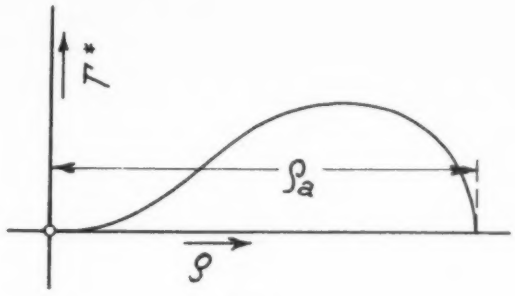


FIG. 4.

Eliminating by Eq. (8a) Γ^* from Eqs. (12) it is possible to give in this theory, for an infinite number of blades, the distribution of velocity and circulation for maximum thrust when the torque is prescribed.

It may be given here, as it will appear again as the first member in the maximum distribution for a finite number of blades

$$\frac{c_m^*}{c} = \frac{\Gamma^*}{4\pi\rho} = \frac{\lambda\rho}{2[1 + \rho^2(1 - \lambda)]} - \frac{\beta}{2} \quad (13)$$

where λ is the Lagrangian factor to be determined by the value of the prescribed torque.

7. Signification and Possible Use of Eqs. (8), (10), and (11)

Eqs. (8), (10), and (11) form a complete set of equations and can now be applied in three different ways to the propeller problem.

7a. *The first and simplest way* is to choose an appropriate distribution $\Gamma^*(\rho)$ then to figure from Eq. (8) the corresponding induced velocities, obtain thrust and torque of the blade by putting Γ^* and c^*/c into Eq. (11) and find the specific blade width t^* by Eq. (10).

This procedure may be illustrated by the following *numerical example:*

Take as a desirable circulation function (Fig. 4)

$$\Gamma^* = g\rho^{\frac{1}{2}}(\rho_a - \rho)$$

where g is a constant to be determined by the value of the torque. This distribution makes Γ^* as it must be, zero at the axis and at the tip $\rho = \rho_a$ and has its maximum at about $^3/_4$ of the radius. This choice of Γ^* makes

$$p^*\tau^{1/3} \equiv U_2 = g\tau^{1/3}(\tau^2 - 1)[25\rho_a(\tau^2 - 1)^{1/3} - 36(\tau^2 - 1)] \quad (2c)$$

Now choose further the reciprocal advance of the tip

$$\rho_a = 3.04 \text{ corresponding to } \tau_a = 3.2$$

Number of blades $l = 3$. Then it may suffice here to give the evaluation of the induced velocity only at one point, $\rho = 2.11$ ($\tau = 2.335$), $r/r_a = 0.695$, that is, at the point where U_2 changes sign. By graphical integration of the integrals of the series it was found that

$$(c^*/c)_{r = 0.695 r_a} = g(5.875 + 1.985)$$

The first figure gives the self-induced relative velocity as it would be generated by an infinite number of blades, and the second the corrections (about 30 per cent) due to the tip loss, which would be greater if a point nearer to the tip had been chosen. In Eq. (8) the series terms show the blade number l as a divisor indicating that with l increasing the tip loss becomes smaller.

Having in this way determined the induced relative velocity, that is the change of angle of incidence, at a sufficient number of points along the blades, the product tc'_a of blade width and lift coefficient derivative can be figured from Eq. (10) and then the data for the construction of the blade are complete.

7b. *The second way* of attacking the problem *starts from given constructional data* such as the velocity w, revolutions ω, blade sections tc'_a and angles i_o, and tries to find the induced velocities c^*, the circulation Γ, and lift distribution dL/dr. The procedure is then to eliminate in Eq. (8) the induced relative velocity c^*/c from Eq. (10) and in this manner obtain an *integral equation* containing as the only unknown function the specific circulation Γ^*. If then, to make this equation more clear, the circulation

$$\Gamma_0^* = (i_0 - \beta)\,\frac{t^*\,(1+\rho^2)^{1/2}}{1 + \dfrac{t^*\,(1+\rho^2)^{1/2}}{4\pi\rho}} \qquad (15)$$

for an infinite number of blades is introduced, the integral equation of this problem takes the form:

$$\Gamma^* = \Gamma_0^* + \frac{2t^*\,(1+\rho^2)^{1/2}/4\pi\rho}{1 + t^*\,(1+\rho^2)^{1/2}/4\pi\rho} \times \left[\sum_{n=1}^{\infty} K_n \int_0^{\rho} I_n d\left(\xi \frac{d\Gamma^*}{d\xi}\right) + I_n \int_{\rho}^{\rho_a} K_n d\left(\xi \frac{d\Gamma^*}{d\xi}\right)\right] \qquad (16)$$

It is very likely that beginning with the circulation corresponding to the mean induced relative velocity

$$c_m^*/c = \Gamma_0^*/4\pi\rho,$$

a second already good approximation Γ^*_1 is obtained by computing the series of integrals appearing in Eq. (16) with Γ_0^* inserted and a third approximation by inserting Γ^*_1 under the integrals. Care probably must be taken to choose the data function tc'_a so that it becomes zero at the tip and at the axis in order to make this successive approximation practically convergent at all points.

7c. *The third equation asking for maximum thrust* may be treated according to the classical theory of the isoperimetric problem.

Calling λ the Lagrangian factor of the condition of prescribed values of torque M^* (Eq. 11), angular velocity ω, speed w, the maximum of thrust T^*, (Eq. 11) demands that

$$\int_0^{\rho_a} d\rho \left[\delta\Gamma^*\{\rho(1-\lambda) - \left(\frac{c^*}{c} + \beta\right)(1+\lambda\rho^2)\} - \delta\left(\frac{c^*}{c}\right)\Gamma^*(1+\lambda\rho^2)\right] = 0 \qquad (17)$$

In Eq. (12a) the variation $\delta\,\dfrac{c^*}{c}$ is not independent of the variation $\delta\Gamma^*$ but connected to it by Eq. (8) and (8a) which show that the change of induced specific velocity c^*/c at any one element of the radius is connected to the changes of specific circulation Γ^* at all elements of the radius along the blades.

For reasons of simplicity and convergence of the necessary summations the two variations $\delta\Gamma^*$ and $\delta\,\dfrac{c^*}{c}$ shall both be expressed by the variation of the fictitious source distribution, by using Eqs. (2) and (3) and changing to dimensionless variables, *viz:*

$$\Gamma^*(\rho) = \int_0^{\rho} \frac{d\xi}{\xi} \int_0^{\xi} d\psi\psi p^* \qquad (2c)$$

and assuming a change of p^* only at one point ψ

$$\left.\begin{aligned} \delta\Gamma^*(\rho) &= \delta p^* \cdot \psi d\psi \; ln\,\frac{\rho}{\psi}, \quad \psi < \rho \\ \delta\Gamma^*(\rho) &= 0, \quad \psi > \rho \end{aligned}\right\} \text{(2d)}$$

so that a variation of p^* in one point ψ produces changes Γ^* in all points ρ inside of ψ.

From Eq. (8) then is deduced:

$$\delta\left(\frac{c^*}{c}\right)_{\rho} = (\delta\Gamma^*)_{\rho}\,\frac{1}{4\pi\rho} - \frac{1}{2\pi\rho}\delta p^*\psi d\psi \sum_{n=1}^{\infty}\left[I_{nl}(nl\psi)K_{nl}(nl\rho) + K_{nl}(nl\psi)I_{nl}(nl\rho)\right]$$

Therefore observing (2d)

$$\left.\begin{aligned} \left(\delta\frac{c^*}{c}\right)_{\rho>\psi} &= \delta p^*\psi d\psi\,\frac{1}{4\pi\rho}\left[ln\,\frac{\rho}{\psi} - 2\sum_1^{\infty} I_{nl}(nl\psi)K_{nl}(nl\rho)\right] \\ \left(\delta\frac{c^*}{c}\right)_{\rho<\psi} &= -\delta p^*\psi d\psi\,\frac{1}{4\pi\rho}\,2\sum_1^{\infty} K_{nl}(nl\psi)I_{nl}(nl\rho) \end{aligned}\right\} \text{(8c)}$$

Introducing these expressions for $\delta\Gamma^*$ and $\delta\,\dfrac{c^*}{c}$ into Eq. (17) there follows the *Integral Equation* of the proposition of *maximum thrust with given torque*, viz:

$$\sum_1^\infty K_{nl}(nl\psi)\int_0^\psi I_{nl}(nl\rho)\Gamma^*(\rho)\frac{1+\lambda\rho^2}{2\pi\rho}d\rho+$$
$$\sum_1^\infty I_{nl}(nl\psi)\int_\psi^{\rho_a} K_{nl}(nl\rho)\Gamma^*(\rho)\frac{1+\lambda\rho^2}{2\pi\rho}d\rho-$$
$$\int_\psi^{\rho_a} d\rho\, ln\frac{\rho}{\psi}\left[\rho(1-\lambda)-\left(\frac{c^*}{c}+\beta\right)(1+\lambda\rho^2)-\Gamma^*(\rho)\frac{1+\lambda\rho^2}{4\pi\rho}\right]=0 \quad (18)$$

As to the convergence of the series terms, the same observations are valid as in Chapter 3a.

To complete the set of equations determining the functions c^*/c and Γ^* and the constant Lagrangian factor λ, Eq. (8) and the second of Eqs. (11) must be added.

This system of Eqs. (18), (8), and (11) does not look inviting. Anyhow there exist solutions for the special cases, first, the very simple Eq. (13) for an infinite number of blades, and then the solution of Betz and Goldstein for profile drag β zero. There is some hope that from these, by successive approximation, solutions might be found.

Letters to the Editor

October 16, 1937

Dear Sir:

In the paper "Two New Longitudinal Stability Constants" by Alexander Klemin and J. G. Beerer, Jr., published in the September issue of the Journal, the two coefficients proposed as criteria of longitudinal stability are obtained by assuming that the number of degrees of freedom of the motion can be reduced from three degrees to a simple pitching motion about the center of gravity.

As a result of this assumption, two conclusions appear obvious: that the period of longitudinal motion is proportional to the square root of the longitudinal moment of inertia and is inversely proportional to the square root of the slope of the pitching moment curve, and that the damping of longitudinal motion is entirely due to the damping of pitch. However, neither of these conclusions apply to actual airplane motion.

That the period of longitudinal motion is practically independent of moment of inertia was shown in flight tests by Norton and Carroll as reported in N.A.C.A. Technical Note 115. In N.A.C.A. Technical Report 172 this conclusion was checked by E. B. Wilson by use of the general theory.

Moreover, the longitudinal period is not proportional to the inverse square root of the slope of the pitching moment curve. If it were, the designer could make the longitudinal period of an airplane as short as he desired. Actually there is a definite minimum period for each flight condition. An increase of the slope of the pitching moment curve beyond the amount required for the minimum period has no effect upon longitudinal motion, but serves only to produce an undesirable increase of the control force required for maneuvering.

The reduction of the number of degrees of freedom taken into consideration also has an important effect upon conclusions regarding the damping of longitudinal motion. When the complete motion is assumed to be reduced to a simple pitching motion about the center of gravity, the only remaining damping term is the one due to pitching velocity. The coefficient proposed is based upon this component of the total damping. Actually, however, due to changes of velocity along the horizontal and vertical axes, there are two additional damping terms in the system.

Unfortunately for the proposed coefficient, the damping due to pitching motion has a very minor effect at cruising speed upon the damping of longitudinal motion. In fact, in low angle of attack flight a good approximation to the damping of the motion can be made by assuming that the damping coefficient is proportional to the airplane drag. Consequently, the proposal to use the damping of pitch as a criterion of damping of longitudinal motion cannot in general be correct and, consequently, can be misleading.

For design purposes, simplification of the rather complicated theory of airplane stability is to be desired. However, such an over simplification leads to results so far from the truth that the designer may be confused about a matter where considerable misconception already exists.

Otto C. Koppen
Massachusetts Institute of Technology

August 19, 1937

Dear Sir:

In the April, 1937 issue of the Journal of The Aeronautical Sciences is a paper on the "Rational Shear Analysis of Box Girders" by Robert S. Hatcher. For the calculation of the total shear forces on the webs of a single-cell box girder, Mr. Hatcher has developed formulae based on the force F applied at the shear center of the girder. If the applied shear does not act through the shear center, the principal of superposition is used to add the torsional shear forces to those calculated by the developed formulae.

Herein is given a method of shear distribution in a single-cell box girder for the force F applied at any point. The method is applied to the identical box girder illustrated in Mr. Hatcher's article and is developed for both the thin and the thick web girder. The total shear loads in the webs are found directly without necessitating the superposition of torsional shear loads as in Mr. Hatcher's article.

Heavily Stiffened Box Girder with Very Thin Webs

In a heavily stiffened box girder with very thin webs (see Fig. 1.):

$$\text{Shear center location } e = \frac{A_2 W}{A_2 + A_1} \quad (1)$$

The shear stresses in the webs are:

(PLEASE TURN TO PAGE 15)

Wind-Tunnel Tests of Air Intake Louvres

JOHN R. WESKE, *Case School of Applied Science*

(Received March 27, 1937)

AIR intakes for cooling or ventilating purposes of aircraft or surface vehicles may be of the projecting type designed to produce a considerable pressure, or else of the flush type. The latter type is advantageous for large intake openings and also in those instances where reduction of drag is essential.

An analysis of the operation of ventilating openings and a large amount of experimental data were presented by F. Rokus and Th. Troller in a recent paper.* These data, however, do not include non-projecting intakes of relatively large size. Since the latter are of considerable practical importance, an experimental investigation of several models of intake louvres with a large number of deflecting vanes was undertaken in the wind tunnel of Case School of Applied Science.

Test Setup

A view of the test setup is shown in Fig. 1. The principal element is a large square box (a) suspended by four wires so that its under side is flush with the ceiling of the working section of the wind tunnel. The louvre models (No. 1b and No. 2c shown in Fig. 1) to be tested are inserted in the bottom of this box, while a measuring nozzle is fastened in the center of the top plate. Above the box there is mounted a fan whose circular suction pipe, d, of a diameter considerably larger than the nozzle extends down almost to the top of the box. A felt seal, e, between this duct and the flat top of the box reduces the air leakage without causing appreciable friction. The arrangement is such that the air leakage does not affect the nozzle measurements. Horizontal wires, f, attached to the box near the bottom lead to a counter weight on downstream side, and on upstream side to a scale, g, which permits measuring the drag of the suspended parts. An adjusting screw and several standard reference marks serve to eliminate any error in the measurement of drag from displacement of the box. Pressure connections are provided on opposite sides of the box just above the louvre, and one each just ahead, and at the throat, of the nozzle. Thus the pressure drop across the louvre and the quantity of flow through the louvre is obtained.

Furthermore, there are windows, h, and holes in the sides of the box a short distance above the louvre for pitot tube and directional measurements.

* F. Rokus and Th. Troller, *Tests on Ventilating Openings for Aircraft*, Journal of the Aeronautical Sciences, Vol. 3, No. 6, April, 1936, pp. 203–208.

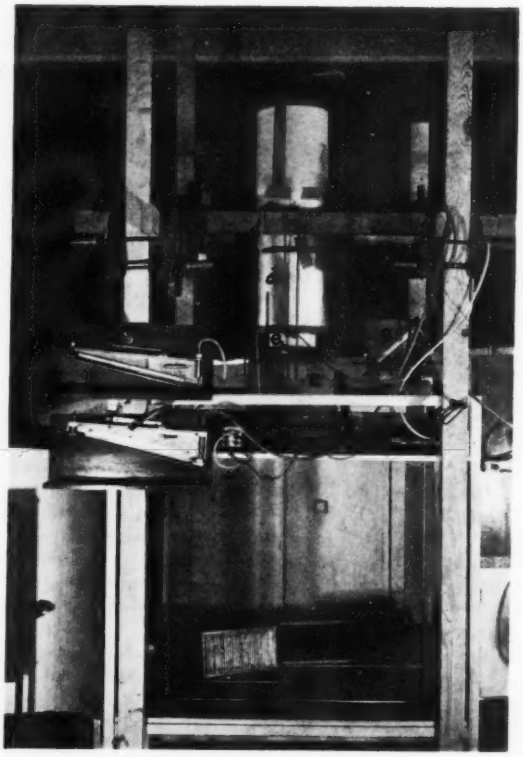


FIG. 1. Test setup for wind-tunnel tests of air intake louvres. a, box for louvre model; b, louvre 1; c, louvre 2; d, suction duct of fan; e, felt seal; f, drag wires; g, scale; and h, windows for pitot and directional measurements.

The three louvre models tested were of different design, but of equal size. Their rectangular opening is 6 × 12 ins., the longer side extending parallel to the airstream. Deflecting vanes of one-half inch chord were placed across the opening parallel to the shorter side. The details of design of these louvres can be gathered from Table 1.

TABLE 1. DIMENSIONS OF LOUVRE MODELS

No.	Opening, Inches	No. of Vanes	Spacing of Vanes, Inches	Chord of Vanes, Inches	Angles of Vanes with Respect to Surface of Louvre: Inlet Side	Outlet Side
1	6 × 12	12	1	1/2	90°	90°
2	6 × 12	24	1/2	1/2	45° upstream	90°
3	6 × 12	12	1	1/2	45° upstream	90°

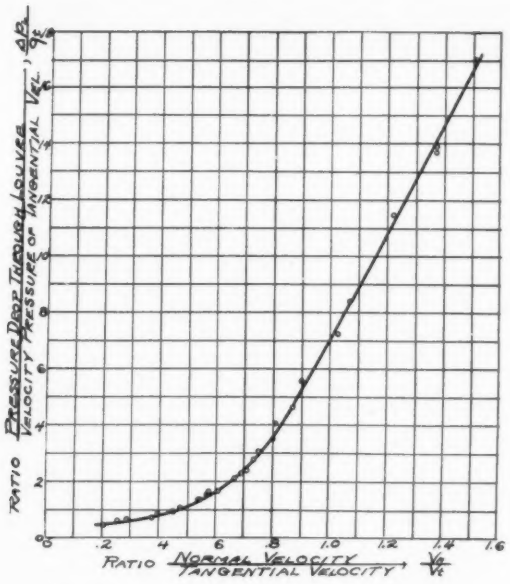

RATIO PRESSURE DROP THROUGH LOUVRE / VELOCITY PRESSURE OF TANGENTIAL VEL., Δp_L/q_t
RATIO NORMAL VELOCITY / TANGENTIAL VELOCITY, V_n/V_t

FIG. 2. Pressure drop coefficients for louvre 1.

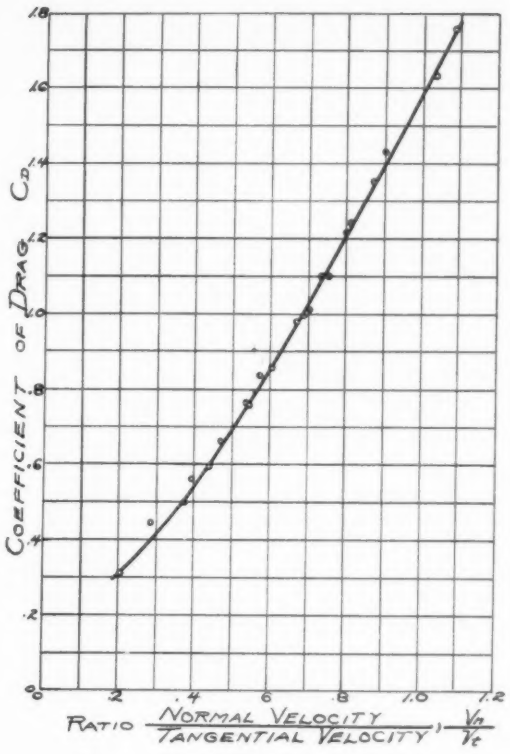


FIG. 3. Drag coefficients for louvre 1.

In addition to placing the louvres flush with the ceiling, certain modifications of the ceiling of the working section were made to test the effect of recessing the louvre and of rounding the edges of the intake opening. The fairing pieces were mounted on the box in order to evaluate the change of drag caused by them. Furthermore, the thickness of the boundary layer was varied within certain limits by placing a deflector at various distances upstream of the box. A small portion of the air of the wind-tunnel stream was thereby diverted through a slot in the ceiling.

Both the wind-tunnel velocity and the velocity through the louvre were varied for each series of runs; the former from zero to approximately 100 ft. per sec.; the latter from zero to 40 ft. per sec., this velocity based on the nominal area of the louvre.

For presentation of the results of the investigation the following denotations are used:

v_t = wind-tunnel speed, ft./sec.
v_n = velocity through louvre, ft./sec. $v_n = Q/A$
Q = quantity of flow through louvre, ft.^{3}/sec.
A = nominal area of louvre, ft.^{2} $A = 6 \times 12$ in. = 0.5 sq.ft.
D = net drag of louvre, including fairings, lb.
Δp_L = static pressure drop across louvre, lb./ft.^{2}
q_t = velocity pressure of wind-tunnel speed, lb./ft.^{2}
$q_t = \rho v_t^2/2$, where ρ = density of air

The results of the tests can advantageously be presented by plotting the dimensionless quantities $\Delta p_L/q_t$, $D/Aq_t = C_D$ and $A\Delta p_L/D$ against the ratio v_n/v_t.

The quantity $A\Delta p_L/D$ is obtained by dividing $\Delta p_L/q_t$ by D/Aq_t. It represents the ratio of the static pressure force acting normal to the louvre to the drag

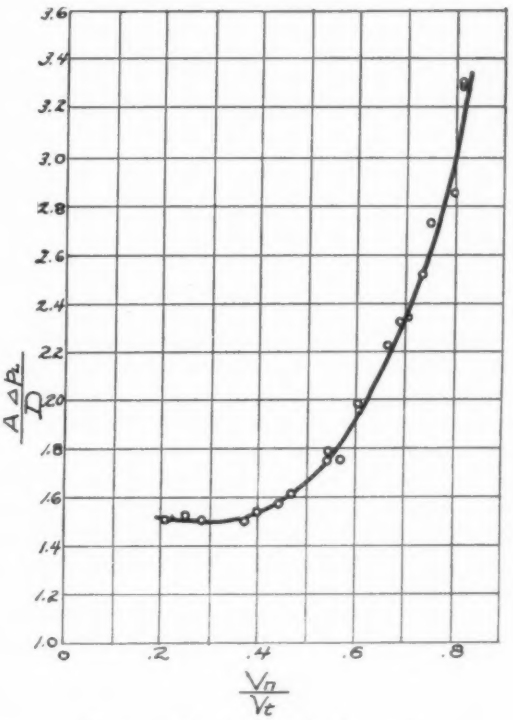


FIG. 4. Ratio $A\Delta p_L/D$ for louvre 1.

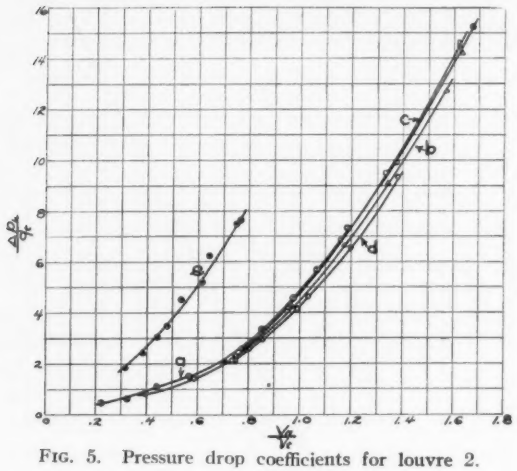


FIG. 5. Pressure drop coefficients for louvre 2.

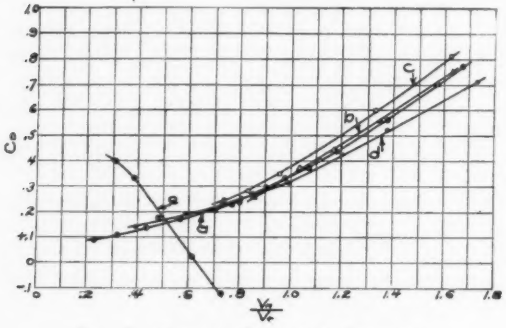


FIG. 6. Drag coefficients for louvre 2.

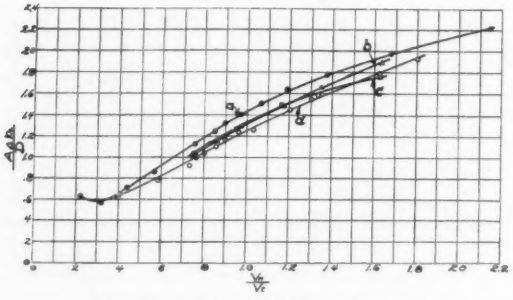


FIG. 7. Ratio $A\,\Delta p_L/D$ for louvre 2.

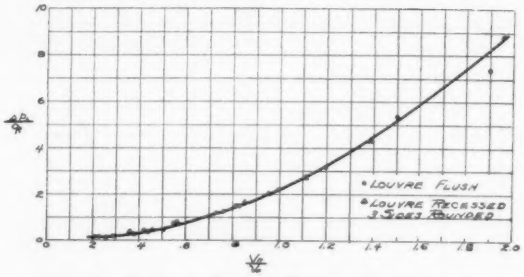


FIG. 8. Pressure drop coefficients for louvre 3.

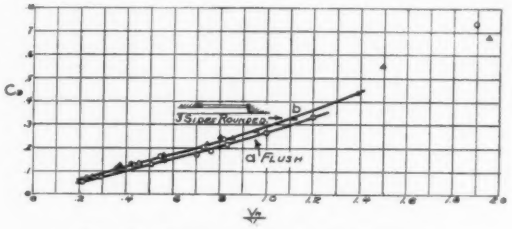


FIG. 9. Drag coefficients for louvre 3.

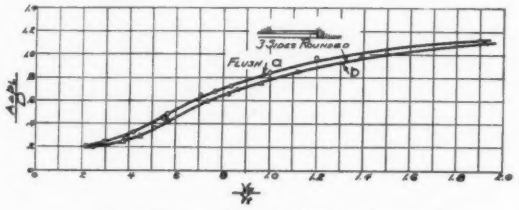


FIG. 10. Ratio $A\,\Delta p_L/D$ for louvre 3.

force acting in the plane of the louvre and may be taken as a measure of the relative effectiveness of the louvre. Since Δp_L denotes the pressure drop through the louvre, it is seen that the performance of the louvre improves as the pressure drops and consequently the value $A\Delta p_L/D$ decreases.

Figs. 2 to 4 show the results of tests of louvre 1; Figs. 5 to 7, those of louvre 2; and Figs. 8 to 10, those of louvre 3. In Figs. 5, 6, and 7, the following is the explanation of the curves:

Curve a. Louvre arranged flush with surface.

Curve b. Louvre recessed $1^1/_2$ in., three sides rounded, downstream side flush.

Curve c. Louvre recessed $1^1/_2$ in., all four sides rounded.

Curve d. Louvre flush with surface. Boundary layer thickness reduced to approximately 1 in.

Curve e. (Figs. 5 and 6 only.) Louvre reversed with respect to direction of wind-tunnel stream. Arranged flush with surface.

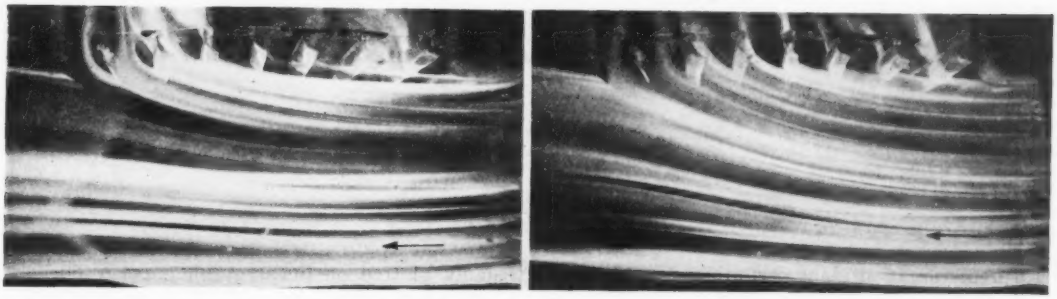
Note that the thickness of the boundary layer is $1^1/_2$ in. approximately, except for curve 5.

The results from these tests may be summed up in the following conclusions:

(1) The performance of the straight vanes of louvre 1 is inferior to that of the forwardly curved vanes of louvres 2 and 3 throughout the entire range investigated. However, its performance exceeds those of the latter for operation in reverse direction, as shown by the test with louvre 2 reversed. (See curves e of Figs. 5 and 6.)

(2) Comparison of the tests of the forwardly curved vanes shows that a spacing equal to twice the blade width gives considerably better results since both the pressure drop across the louvre and the drag are reduced.

(3) For the proportions of the intake openings adopted for these tests a slight improvement of the flow through the louvre was obtained by rounding off the sides parallel to the flow, as shown by curves b of Figs. 7 and 10. Another slight gain is recorded when recessing the louvre and rounding the upstream



FIGS. 11 and 12. Smoke pictures of flow through a louvre model.

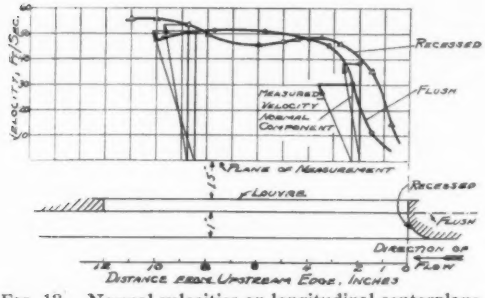


FIG. 13. Normal velocities on longitudinal centerplane of louvre 2 for louvre in flush position and in recessed position. Ratio of velocities $v_n/v_t = .85$.

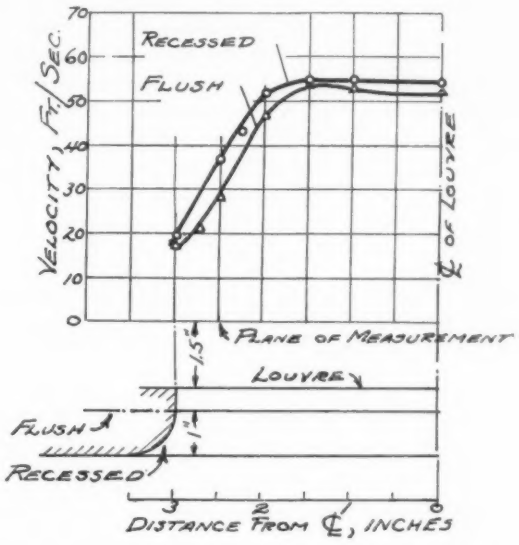


FIG. 14. Normal velocities through louvre 2 in a transverse plane 4.5 in. aft of upstream edge, for louvre in flush position and in recessed position. Ratio of velocities $v_n/v_t = .85$.

edge and the sides. This is brought out by curve c of Fig. 7. Fairing all four sides, however, fails to produce a further gain. (See curve d, Fig. 7.)

(4) A decrease of the boundary layer thickness from 1.5 in. to 1 in. proved very effective in increasing the performance of the vanes. (Cf. curves e and a, Fig. 7.)

(5) While an improvement of the $A\,\Delta p_L/D$ values was noticed as the wind-tunnel speed and the velocity through the louvre was increased for constant v_n/v_t, the difference resulting from change of Reynolds Number was so small that it could not be evaluated quantitatively.

The results obtained from the tests described thus far made further investigations of the distribution of flow through the louvres advisable. A visual study of the flow was made in a smoke tunnel with a set of vanes of the same size as those of the louvre. Typical photographs are shown in Fig. 11 for a smaller value of v_n/v_t, and in Fig. 12 for a larger value of v_n/v_t. It is seen that in both cases the stream does not uniformly fill the space between the deflecting vanes. Furthermore, these photographs show that the quantity of air entering the louvre varies greatly along the length of the louvre, suggesting that the effect of the vanes is cumulative in character.

Further facts regarding the distribution of flow through the louvre were obtained from pitot tube traverses taken inside the box in a horizontal plane $1^1/_2$ in. above the louvre. The pitot tube was adjusted tangential to the stream with the aid of a small vane. Fig. 13 shows the distribution of normal velocities on longitudinal centerline of louvre 2, and also, the improvement through recessing at the upstream edge by comparison of curves b and a. Measurements of normal velocity across the width of the louvre (Fig. 14), reveal that a considerable contraction of the airstream takes place. The contraction can be diminished slightly, however, by fairing the sides, as shown by curve b of the same figure.

Inasmuch as all louvres thus far tested show a considerable variation of velocity along the length of the louvre, it was not deemed feasible to analyze the action of the vanes in the manner applied to airfoil grids operating in a uniform stream.

An Airplane Performance Slide Rule

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(Received May 28, 1937)

THE prediction of airplane performance is a lengthy process by conventional methods. This paper presents a modification of the conventional method which greatly shortens the time required to make an estimation. This method is based on the use of logarithmic instead of linear coordinates for plotting the airplane-power-required curve and the propeller-power-available curve. It will be shown that all airplanes can be represented by one power-required curve and that standard propeller curves can be used to represent most fixed-pitch and constant-speed propellers.

Basic Chart

Airplane performance is usually estimated by drawing curves of horsepower or drag and thrust *versus* speed for the airplane and propeller. These are usually plotted on linear graph paper. The author's method is based on the use of logarithmic graph paper such as that shown in Fig. 1. This is a chart of speed *versus* drag divided by weight. Lines of constant horsepower divided by weight are plotted on the chart. Horizontal lines are labeled with values of D/L and its reciprocal L/D. On the right values of $\tan^{-1}(D/L)$ are listed. The hp./lb. lines are labeled with hp./lb. and ft./min. scales where the value of ft./min. is that corresponding to the value of hp./lb. These velocities are the sinking or rising speeds of the plane. The angles are the gliding or climbing angles.

Airplane Power Required

The power required by the airplane is shown in T.R. 408 to be expressed by the equation:

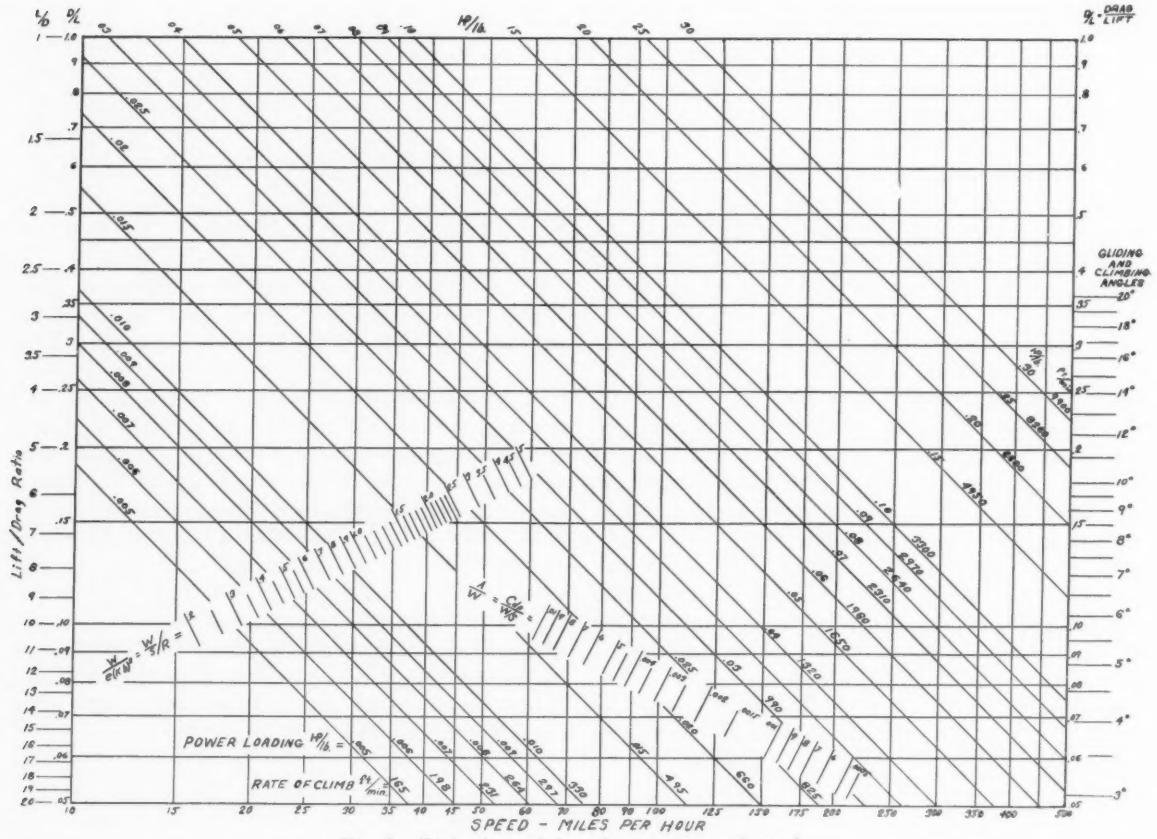

FIG. 1. Basic chart of drag, horsepower, and speed.

$$\frac{D}{W} = \frac{D_i}{W} + \frac{D_p}{W} = \frac{W}{\frac{\rho}{2}\pi e(Kb)^2 V^2} + \frac{Cdp}{(W/S)}\frac{\rho}{2}V^2$$

and

$$\frac{D_i}{W} = \frac{W}{e(Kb)^2}\frac{1}{\pi\frac{\rho}{2}V^2}; \frac{D_p}{W} = \frac{Cdp}{(W/S)}\frac{\rho}{2}V^2$$

When curves of D_i/W and D_p/W are plotted on Fig. 1 it is found that they are straight lines with -2:1 and 2:1 slopes, respectively. Scales of $W/e(Kb)^2$ and $Cdp/(W/S)$ where the D_i/W and D_p/W lines cross the scales with $\rho = \rho_o = .002378$ have been placed on Fig. 1. In Fig. 2 lines at -2:1 and 2:1 slopes are drawn alone with a vertical and a horizontal line. When Fig. 2 is drawn on transparent paper or celluloid it can be superimposed on Fig. 1 so that the sloped lines D_i and D_p pass through the desired values of $W/e(Kb)^2$ and $Cdp/(W/S)$. These lines then represent the induced and profile drags of the plane at sea level. The sum of D_i/W and D_p/W or D_T/W is the line D_T on Fig. 2 and since it has a fixed relation to lines D_i and D_p its location over Fig. 1 is determined by locating the lines D_i and D_p as specified above. Thus D_T is a curve of drag/weight *versus* speed at sea level for any airplane. This curve is reasonably accurate for all airplanes except near the stall.

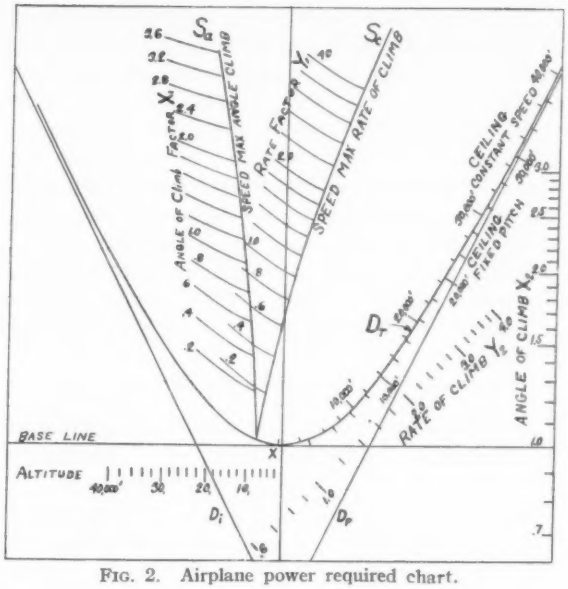

FIG. 2. Airplane power required chart.

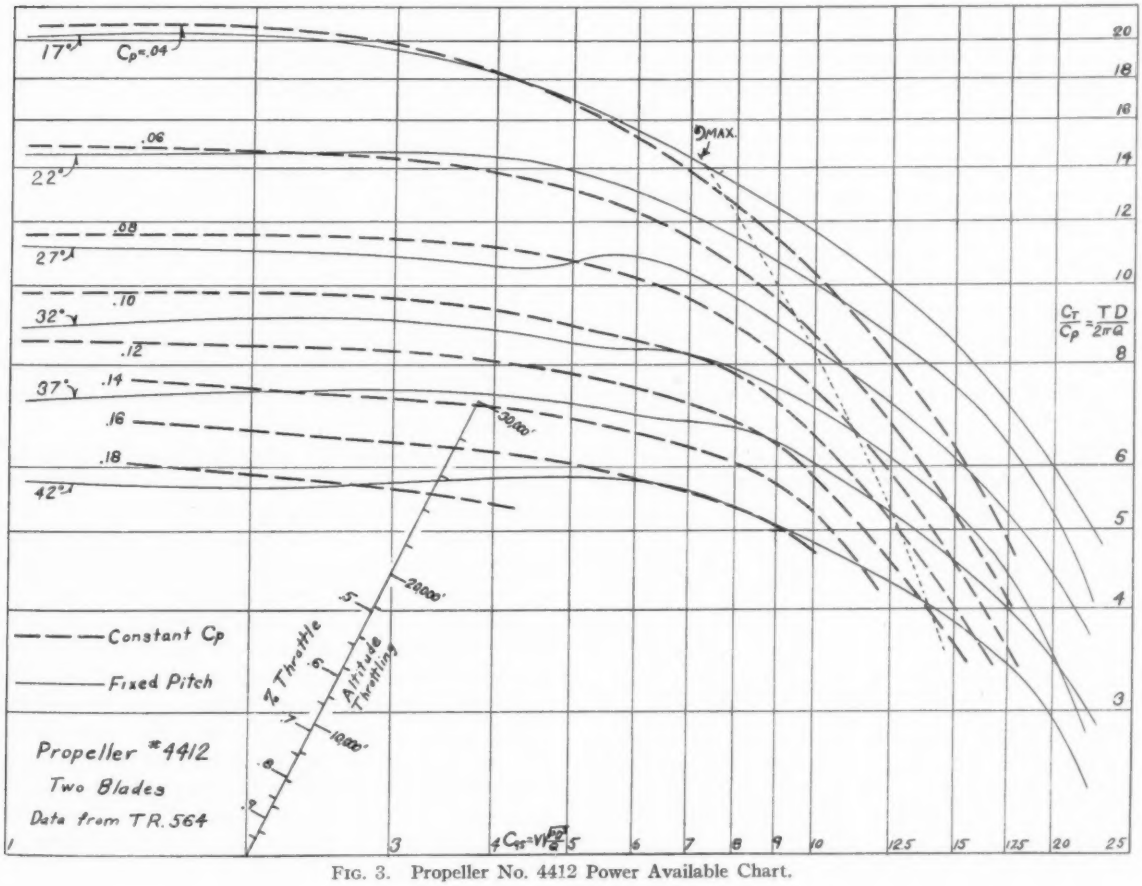

FIG. 3. Propeller No. 4412 Power Available Chart.

For any point on curve D_T the corresponding speed, sinking speed, required hp./W, D/L, L/D, and gliding angles can be read directly on the scales of Fig. 1 for sea level conditions. At altitude the D/L, L/D, gliding angles, etc. do not change from those at sea level. Hence the chart can have no vertical motion when being moved to represent altitude conditions. The speed for any given condition increases as $\sqrt{\rho_0/\rho}$ or $1/\sqrt{\sigma}$ and the chart must be moved to the right by this amount to represent altitude conditions. Along the bottom of Fig. 2, a scale of $1/\sqrt{\sigma}$ has been plotted to facilitate the altitude shift.

Propeller Power Available

Propeller thrust *versus* speed curves can be obtained on the basis of the method presented by Hartman in T.R. 487. Curves of $C_T/C_p = TD/2\pi Q$ *versus* $C_{qs} = V\sqrt{\rho D^3/Q}$ for several blade angles are plotted in Fig. 3 to logarithmic scales. These are curves of thrust *versus* speed for fixed pitch, density, and torque. Constant-speed propellers can be represented on Fig. 3 by drawing lines of constant C_p. These must be interpolated from the fixed-pitch curves and the values of $C_p = P/\rho N^3 D^5$ for the various points along them.

To represent the T/W *versus* V curve for any propeller, Fig. 3 can be traced on celluloid and superimposed on Figs. 1 and 2. It is necessary to locate the chart by first calculating some point on the chart. The propeller data used to draw Fig. 3 is taken from T.R. 564 and is for the 4412 propeller on a nacelle and wing.

When Fig. 3 has been properly located over Figs. 1 and 2 the thrust-speed curves of two-speed propellers with constant throttle setting can be read directly from the curves for the desired angles. The thrust-speed curves for constant-speed propellers at various r.p.m. values can be read as those at the desired C_p values. It is to be noted that the chart position is determined by Q, ρ, D, and W and that r.p.m. and blade angle do not affect its location. Any given point represents a fixed value of C_{qs} and C_T/C_p or $V\sqrt{\rho D^3/Q}$ and $TD/2\pi Q$. Let the torque variations with altitude and throttle setting be $Q/Q_0 = f$ and the density variations with altitude be $\rho/\rho_0 = \sigma$.

$$C_{qs} = V_0\sqrt{\frac{\rho_0 D^3}{Q_0}} = V\sqrt{\frac{\rho D^3}{Q}} \text{ and } \frac{C_T}{C_p} = \frac{T_0 D}{2\pi Q_0} = \frac{TD}{2\pi Q}$$

or

$$\frac{V}{V_0} = \sqrt{\frac{\rho_0 Q}{\rho Q_0}} = \sqrt{\frac{f}{\sigma}} \text{ and } \frac{T}{T_0} = \frac{Q}{Q_0} = f$$

The propeller chart (Fig. 3) thus has a shift to the right of $\sqrt{1/\sigma}$ when going to altitude which is identical to that of the airplane chart, and a motion parallel to the D_p line for throttle or torque variations due either to altitude or throttle variations. The amount of this shift is shown on the throttle scale on Fig. 3. The density shift is made by moving the airplane and propeller charts together.

Charts such as Fig. 3 can be drawn for various propellers as data becomes available. If the propeller efficiency is different from the test values plotted the correction can be made by a vertical shift of Fig. 3. Multiple propellers can be expressed by shifting the chart vertically by the number of propellers. Such multiplications are made on the charts as on a normal slide rule.

It has been shown above that standard airplane and propeller curves can readily be located over a basic chart to give thrust-speed and drag-speed curves. The intersection of these lines is the high speed. The rate of climb at any speed is the difference between the required hp./W and available hp./W or the excess hp./W. Thus the rate of climb is the vertical speed corresponding to the difference in hp./W values of the propeller and airplane at any given speed. On Fig. 2 curves have been drawn for constant rates of climb in terms of the rate of descent at maximum L/D. Thus at any speed the propeller thrust curve crosses the rate of climb curves at some given value which multiplied by the rate of descent at maximum L/D will give the rate of climb at that speed. This is accomplished by reading the value of Y_1 where the thrust curve crosses and then reading the rate of climb on Fig. 1 opposite the scale Y_2 on Fig. 2 where $Y_1 = Y_2$. The speed for maximum rate of climb is nearly expressed for all propellers by the line S_c where the speed is that where the propeller curve crosses S_c.

The angle of climb can be found in a similar manner by reading on scale X, the ratio of

$$\frac{\text{angle of climb}}{\text{angle of descent at } (L/D) \text{ maximum}}$$

and then reading the actual angle of climb on Fig. 1 opposite the X_2 scale on Fig. 2 where $X_1 = X_2$. The line S_a is the speed for best angle of climb. This gives a very rapid method for evaluating angles and rates of climb.

It was shown that the only relative motion between Figs. 2 and 3 when shifting to altitude conditions is that due to throttle setting or altitude throttling. The ceiling occurs when the thrust and drag curves become tangent. It can be shown that for any given propeller and variation of torque with altitude, the ceiling is a function only of the ratio of high speed at sea level to the speed for maximum L/D at sea level where the maximum speed is that which is obtained with the engine giving its full power. This ratio is represented on Fig. 2 by the point where the propeller curve crosses the airplane curve for full throttle at sea level. Along curve D_T on Fig. 2 values of ceiling for an average fixed-pitch and an average constant-speed propeller have been listed. These vary but little between different propellers.

The shifts of the charts when using supercharged engines must be made judiciously so as to take account of actual engine torque variations with altitude. For normal engines with fixed throttle setting the torque variation with altitude is roughly expressed as $f = 1.088\sqrt{\frac{T_0}{T_a}}\frac{p_a}{p_0} - .088$. This does not hold for engines with turbo-superchargers or for engines with centrifugal superchargers below their critical altitude.

In using the propeller charts it is necessary to modify the efficiencies to the case at hand. As more data becomes available it is probable that propeller curves for most propellers can be standardized and that simpler methods of applying them to the logarithmic method given above will be allowable.

The value of $Cdp/(W/S)$ for locating the airplane chart is a measure of cleanness and can be broken down into a wing part and fuselage part where the wing part is $Cdp_{wing}/(W/S)$ and the fuselage part is $S \times Cdp_{fuselage}/W$. The fuselage part $SCdp_F/W$ has been evaluated for a number of airplanes and varies from $SCdp_F/W = .0006$ to $.0060$ depending on how well the ship is streamlined.

(CONTINUED FROM PAGE 7)

$$q_1 = \frac{F}{t_1 h}\left[\frac{A_1}{A_1 + A_2} - \frac{(y-e)}{2W}\right]; \quad q_2 = \frac{F}{t_2 h}\left[\frac{-A_2}{A_1 + A_2} - \frac{(y-e)}{2W}\right]$$

$$q_3 = \frac{-F}{t_3 h}\left[\frac{y-e}{2W}\right]; \quad q_4 = \frac{-F}{t_4 h}\left[\frac{y-e}{2W}\right]$$

The total shear load in each web is equal to:

$$S_1 = F\left[\frac{A_1}{A_1 + A_2} - \frac{(y-e)}{2W}\right] \tag{2}$$

$$S_2 = F\left[\frac{A_2}{A_1 + A_2} + \frac{(y-e)}{2W}\right] \tag{3}$$

$$S_3 = -F\left[\frac{(y-e)}{2h}\right] \tag{4}$$

$$S_4 = -F\left[\frac{(y-e)}{2h}\right] \tag{5}$$

By Eqs. (1) to (5) the shear center and the total shear loads may be calculated without the necessity of knowing the thickness of the webs. The geometry of the girder, the area of the flanges, and the location of the applied load are the only data required. It may be noticed that for a thin web box girder the thickness of the webs may be varied without changing the total shear loads in the webs, providing the applied load remains at the same point.

Heavily Stiffened Box Girder with Webs Effective in Bending

In a heavily stiffened box girder with webs effective in bending (see Fig. 2.):

Moment of Inertia of Box Beam =

$$I = (h^2/2)[(A_1 + A_2 + t_3 W + (h/6)(t_1 + t_2)]$$

Point of Zero Shear in Horizontal Webs =

$$a = \frac{yI}{t_3 h^2 W} - \frac{A_2}{2t_3} - \frac{t_2 h}{12 t_3} + \frac{W}{4} \tag{6}$$

The shear stresses at the different points of the webs are:

$$q_1 = 0, \; q_2 = \frac{Fah}{2I}, \; q_3 = \frac{Fh(t_3 a + A_2)}{2t_2 I}, \; q_4 = \frac{Fh(t_3 a + A_2 + t_2 h)}{2t_2 I}$$

$$q_5 = q_3, \; q_6 = -q_2, \; q_7 = 0, \; q_8 = \frac{Fh(t_3 W - t_3 a)}{2t_3 I}$$

$$q_9 = \frac{Fh(t_3 W - t_3 a + A_1)}{2t_1 I}, \; q_{10} = \frac{Fh[t_3 W - t_3 a + A_1 + (t_1 h/4)]}{2t_1 I}$$

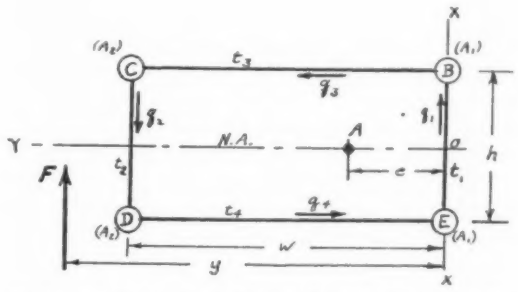

FIG. 1. A = shear center at distance e from axis x–x. Other notations are same as used in Mr. Hatcher's article.

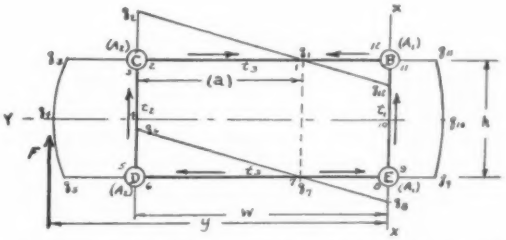

FIG. 2. Distance (a) from CD is point of zero shear in horizontal webs.

$$q_{11} = \frac{Fh(t_3 W - t_3 a + A_1)}{2t_1 I}, \; q_{11} = q_9, \; q_{12} = -q_8$$

The total shear load in each web is equal to:

$$S_1 = (Fh^2/2I)[t_3(W - a) + A_1 + (t_1 h/6)] \tag{7}$$

$$S_2 = (Fh^2/2I)[t_3 a + A_2 + (t_2 h/6)] \tag{8}$$

$$S_3\,(BC) = (Fht_3 W/4I)[2a - W] \tag{9}$$

$$S_4\,(DE) = -S_3 \tag{10}$$

Given the location of the applied load, the point of zero shear in the upper and lower webs is determined from Eq. (6) and then the total shear loads in all the webs are obtained by Eqs. (7) to (10). It is not necessary to find the shear center of the box as it is by Mr. Hatcher's method. The effect of shear due to torsion and shear due to vertical load are combined and the total shear loads in the webs are found directly.

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The Design of Flexure Pivots

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(Received June 30, 1937)

Introduction

THE idea of supporting the moving parts of sensitive instruments on thin strips of metal or other elastic material rather than on knife edges or jewelled bearings, is not new. The advantages were clearly demonstrated by the Emery Testing Machine built in 1897.[1] Most aeronautical engineers are familiar with the Zahm Wind Tunnel Balance[2] in which the fulcrums of the weighing system consist of flexible pieces of steel. It is a significant fact that this device is essentially free from the hysteretic effect caused by the friction and lost motion which occurs in other types of pivots and bearings.

The author has recently designed a new six-component wind-tunnel balance for the University of Washington in which flexure pivots are used in various ways, and to the exclusion of all others. The simple but comprehensive method of analysis which will be described here, is an outgrowth from the more cumbersome methods which were used to design the numerous flexures for this balance.

Types of Flexure Pivots

The simplest and most common type of flexure pivot consists of a thin metal strip which is free to bend as indicated in Fig. 1. Frequently two of these, one at right angles to the other, are machined out of a rod as shown in Fig. 2. This provides ball and socket action in rods subjected to tension or compression, and having only a negligible amount of movement. In some cases it is not necessary to go to the expense of cutting the two right angle flexures, because ball and socket action can be obtained by simply turning down the rod to a small diameter. This results in a single round flexure which can bend equally well in any direction, but it will be stiffer than the thin rectangular flexures unless it can be made longer.

Single flexures will not stand a large transverse load, and even a small one produces a tendency to rotate which is difficult to compensate for. For this reason the combination of four flexures shown in Fig. 3, is used for the main fulcrums of beams in the new wind-tunnel balance at the University of Washington. This combination results in a pivot which is very rigid in all directions and which has a definite center of rotation regardless of the direction and magnitude of the applied load.

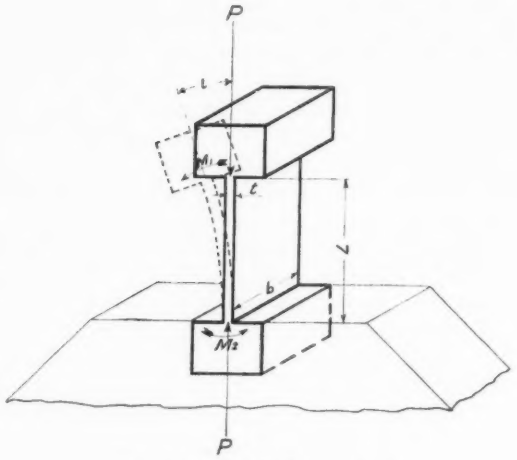


FIG. 1. A simple flexure pivot.

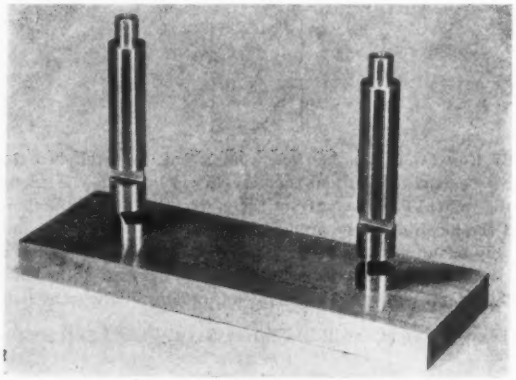


FIG. 2. Double flexures provide ball and socket action. One of these has been tested to destruction.

Many combinations of single flexures may be devised for different purposes. The tripod arrangement shown in Fig. 4, was found to be very helpful because it provides frictionless ball and socket action between parts A and B while the center of rotation is at the intersection of the centerlines of the three flexure rods. This center is shown in the photograph by the three pointers, which are temporarily clamped on. It is adjusted to coincide with the intersection of the pitching and yawing axes about which the model will

[1] C. H. Gibbons, *Materials Testing Machines*, Instruments, Vol. 8, No. 3, pp. 76–78, March, 1935.

[2] N.A.C.A. Technical Report No. 146.

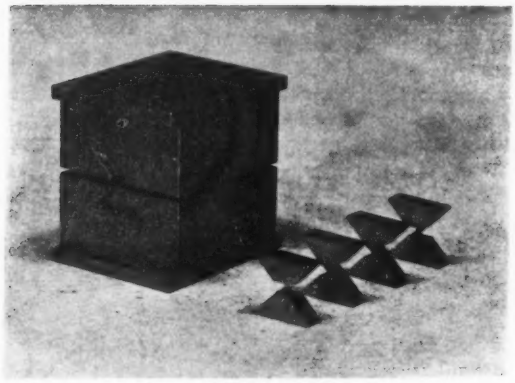


FIG. 3. This combination of flexures will withstand a heavy load in any direction.

turn. This enables moments to be measured about a point, in the model, twelve inches above the measuring equipment.

STIFFNESS OF FLEXURE PIVOTS

When a flexure pivot is rotated as in Fig. 1, the bending stresses in the material produce a restoring moment proportional to the angle of rotation. Except in cases where this angle is extremely small, the restoring moment will offer much greater opposition to rotation than the friction of an equivalent knife edge or jewelled bearing. This does not mean that flexures cannot be used where absolute freedom of rotation through several degrees is necessary, because there are various ways of introducing sufficient instability to compensate for the stability resulting from the stiffness of a flexure. For example, if part A in Fig. 4 is held fixed, and weights are piled on top of part B a condition of neutral stability can be reached such that rotation about the vertical axis is absolutely unopposed.

With the aid of ordinary beam theory, it is a simple matter to compute the stiffness of a flexure if it is subjected to little or no load, but if it is heavily loaded in compression, its stiffness will be greatly reduced and may even be zero or negative. Negative stiffness indicates instability resulting from column action. On the other hand if the flexure is heavily loaded in tension, its stiffness increases and may become many times its no-load magnitude.

If the methods used to analyze axially loaded beams, are applied to the pivot shown in Fig. 1, the following convenient equations may be derived for the stiffness based upon the moment M_1, at the upper or free end.[3]

If P is zero	$M/i = EI/L$
If P is compression	$M/i = \sqrt{EIP}\cot(L\sqrt{P/EI})$
If P is tension	$M/i = \sqrt{EIP}\coth(L\sqrt{P/EI})$

[3] Fred Scoville Eastman, *Flexure Pivots to Replace Knife Edges and Ball Bearings*, University of Washington Engineering Experiment Station, Bulletin No. 86.

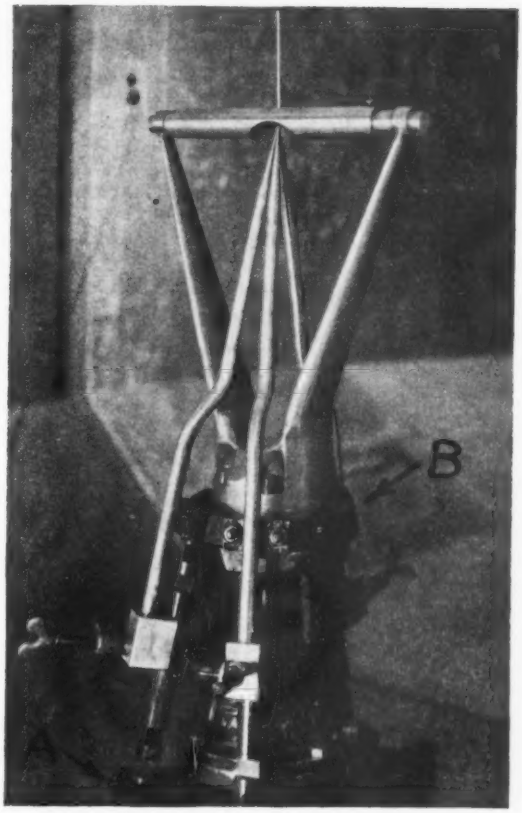


FIG. 4. A flexure tripod provides ball and socket action about a distant point.

In these equations M is the bending moment in inch pounds, i is the angle in radians, E is the modulus of elasticity, I is the moment of inertia about the neutral axis of the flexure, P is the end load in pounds, and L is the length of the flexure in inches.

To reduce the computation required, the right-hand sides of these equations may be expressed in terms of the stress, $f_p = P/A$, and the ratio of the length to the radius of gyration, L/ρ. When this is done, the product, LA, appears as a third variable. Since this is the volume of the flexure, it is convenient to transpose it to the left side of the equation, giving the stiffness per unit volume.

If P is zero	$M/vi = E/(L/\rho)^2$
If P is compression	$M/vi = \sqrt{Ef_p}/[(L/\rho)\tan(\sqrt{f_p/E}\,L/\rho)]$
If P is tension	$M/vi = \sqrt{Ef_p}/[(L/\rho)\tanh(\sqrt{f_p/E}\,L/\rho)]$

These expressions are plotted in Fig. 5 using $E = 29{,}000{,}000$, and choosing several different values of L/ρ. Since most flexures are rectangular in section, a similar set of curves for different values of length divided by thickness have been indicated by the dotted lines.

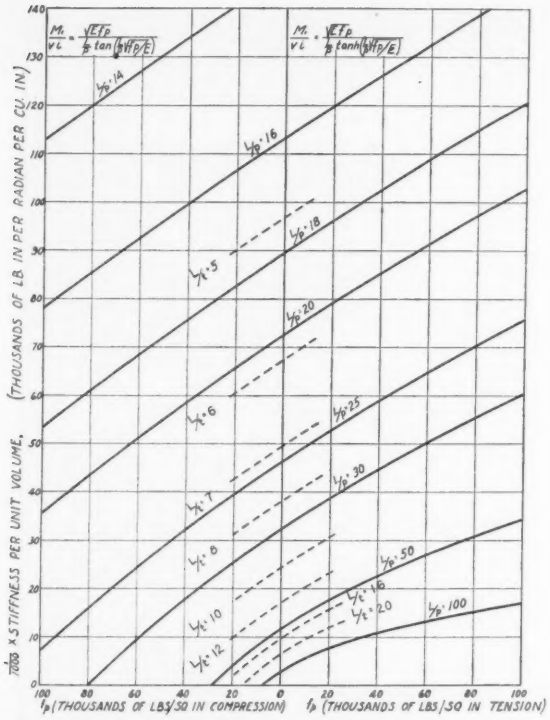

(THOUSANDS OF LB IN PER RADIAN PER CU IN)
1000 X STIFFNESS PER UNIT VOLUME,
f_p (THOUSANDS OF LBS/SQ IN COMPRESSION)
f_p (THOUSANDS OF LBS/SQ IN TENSION)

FIG. 5. Stiffness of single flexures without lateral restraint. (E = 29,000,000)

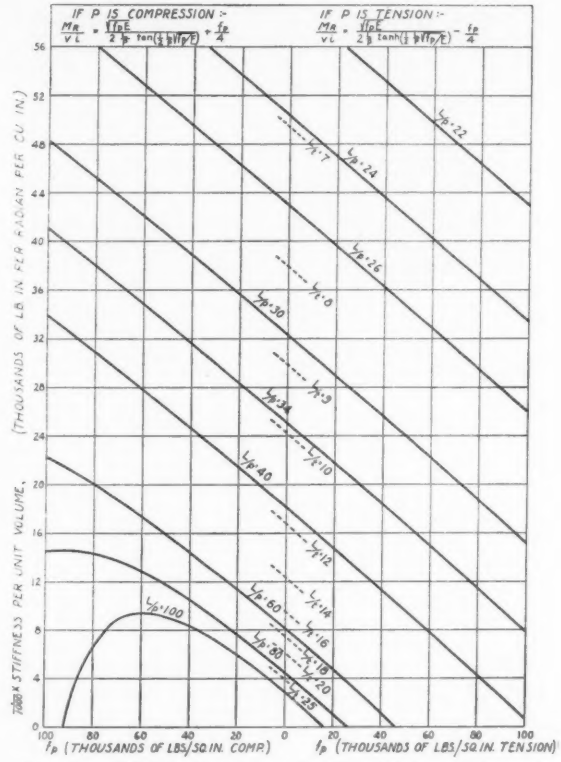

IF P IS COMPRESSION :-
IF P IS TENSION :-
(THOUSANDS OF LB IN PER RADIAN PER CU IN)
1000 X STIFFNESS PER UNIT VOLUME,
f_p (THOUSANDS OF LBS/SQ.IN. COMP)
f_p (THOUSANDS OF LBS/SQ.IN. TENSION)

FIG. 6. Stiffness of flexures having definite centers of rotation located at their midpoints. (E = 29,000,000)

If E is not 29,000,000, it is only necessary to multiply both scales by $E/29{,}000{,}000$. For example, the chart shows that a pivot having an L/ρ of 30, and subjected to 30,000 lbs. per sq.in. tension, will have a stiffness of about 42,000 in. lbs. per radian per cu. in. A pivot of the same dimensions but made out of a material having a modulus of elasticity of 14,500,000, would have a stiffness of about 25,000 when subjected to the same tension. This is determined by following up the 60,000 lbs. per sq.in. tension, and finding a stiffness of 50,000. Since E is half that used for the chart, these figures must be multiplied by one-half, giving the result stated.

The stiffness of flexure pivots of the type shown in Fig. 3 cannot be determined from Fig. 5 because each flexure is constrained by the others to rotate about a fixed center, instead of being free to bend as it will. Moreover, it is necessary to determine the stiffness based upon the restoring moment about this fixed center, instead of that based upon the bending moment at one end, as in the previous case. The following equations may be used for this purpose:[3]

If P is zero $\quad M/i = EI/L$

If P is compression $\quad M/i = PL/4 + (\sqrt{EIP}/2)\cot(\sqrt{P/EI}\,L/2)$

If P is tension $\quad M/i = -PL/4 + (\sqrt{EIP}/2)\coth(\sqrt{P/EI}\,L/2)$

Treating these equations as before gives:

If P is zero $\quad M/vi = E/(L/\rho)^2$

If P is compression $\quad M/vi = f_p/4 + \sqrt{Ef_p}/[(2L/\rho)\tan(\sqrt{f_p/E}\,L/2\rho)]$

If P is tension $\quad M/vi = -f_p/4 + \sqrt{Ef_p}/[(2L/\rho)\tanh(\sqrt{f_p/E}\,L/2\rho)]$

Fig. 6 shows the variation of the stiffness per unit volume obtained from these equations, using the same method of presentation as before. The fact that these curves are straighter than those in Fig. 5, indicates that for great sensitivity, this type of pivot is better than the simple single flexure because it is possible to compensate for stiffness more accurately. By applying the load slightly above the center of rotation, it will tend to make the pivot unstable and this instability will vary directly with the load so that if properly adjusted, it will just neutralize the variation of stiffness of the flexures with load. This results in a constant stability which can be overcome by attaching a fixed weight above the center of rotation. Another way to accomplish the same thing is to turn the pivot shown in Fig. 3 on edge, so that the load tends to slide one block past the other. If this is done, one pair of flexures receives as much tension as the other pair receives compression, and the result is that the overall stiffness remains almost exactly constant.

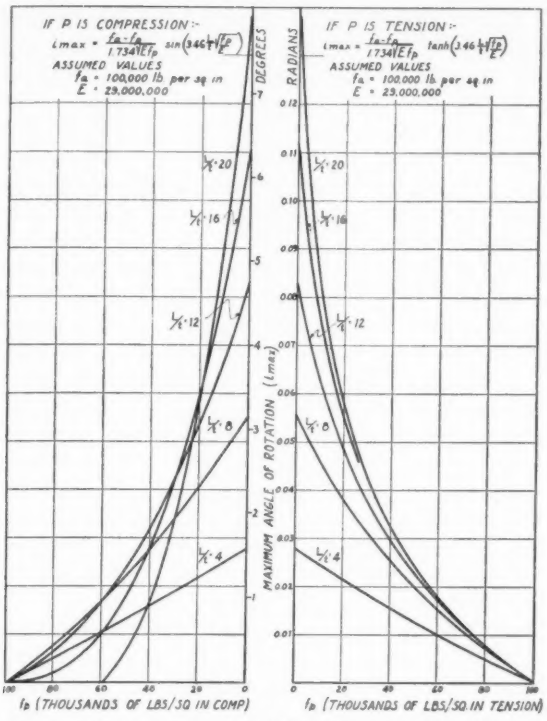


FIG. 7. Maximum rotation of single flexures without lateral restraint. (This chart does not apply to flexures which are not rectangular in cross-section.)

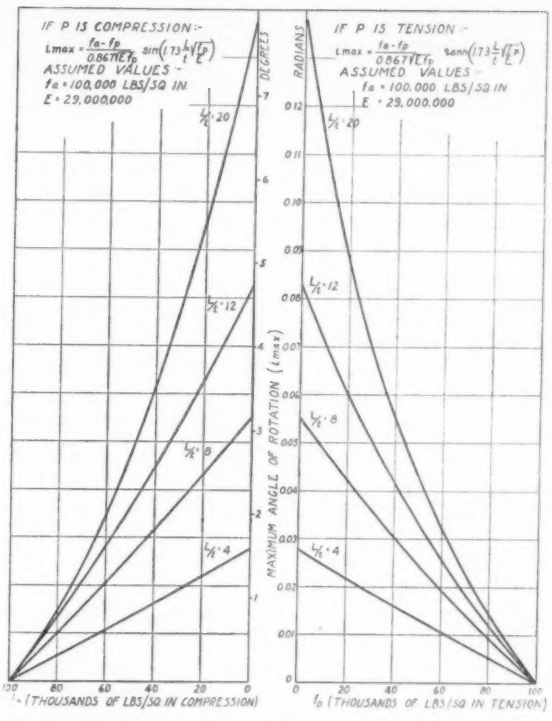


Fig. 8. **Maximum** rotation of flexures having definite centers of rotation located at their midpoints. (This chart does not apply to flexures which are not rectangular in cross-section.)

Strength and Maximum Angle of Rotation

A flexure pivot might be analyzed as a column to determine the maximum load which it would support, but this is of no importance because it cannot function as a pivot when loaded so heavily. Depending upon the material and the type of service demanded of the pivot, a certain fraction of the yield stress may be chosen, which must not be exceeded at any point in the flexure, whether the load is tension or compression. If the flexure is supporting no load it may be bent until the extreme fibers reach this allowable stress, but if it is supporting a load which subjects it to one-third of the allowable stress, then only the remaining two-thirds may be used for bending. As a result, the maximum allowable load depends upon the angle of rotation, and the maximum angle of rotation depends upon the load applied.

The allowable angle may be computed from the stress occurring at the point of maximum bending moment. In single flexures this occurs at one end, if the load is tension, and at the other end, if the load is compression. Letting f_a be the allowable stress and f_p that due to the load, the maximum angle is reached when the bending stress is $My/I = f_a - f_p$. The maximum bending moment is, $M = i\sqrt{EIP}\ \csc\ (L\sqrt{P/EI})$, if the load is compression, and if it is tension, the maximum moment may be obtained from the stiffness equation. Inserting the proper value of maximum moment and solving for the angle gives,

If P is zero $\quad i = Lf_a/Ey$

If P is compression $\quad i = (1/y)(f_a - f_p)\ \sqrt{I/EP}\ \sin(L\sqrt{P/EI})$

If P is tension $\quad i = (1/y)(f_a - f_p)\ \sqrt{I/EP}\ \tanh\ (L\sqrt{P/EI})$

Most pivots are made with rectangular cross-sections so that the distance from the neutral axis to the extreme fiber, expressed in terms of the thickness, is, $y = t/2$. Using this and simplifying as before, the following expressions for maximum angle of rotation are obtained.

If P is zero $\quad i = 2(L/t)(f_a/E)$

If P is compression $\quad i = (f_a - f_p)(1/\sqrt{3Ef_p})\ \sin\ (2\sqrt{3f_p/E}\ L/t)$

If P is tension $\quad i = (f_a - f_p)(1/\sqrt{3Ef_p})\ \tanh\ (2\sqrt{3f_p/E}\ L/t)$

The curves in Fig. 7 have been computed from these and afford a quick method of determining the allowable angle of rotation, assuming that the allowable stress is 100,000 lbs. per sq.in. If a different allowable stress is chosen, the angle obtained from the curves must be multiplied by $(f_a - f_p)/(100{,}000 - f_p)$.

For pivots with circular cross-sections the equations for maximum angle are,

If P is zero $\quad i = 2(L/d)(f_a/E)$

If P is compression $\quad i = (f_a - f_p)/2\sqrt{Ef_p}\,\sin(4\sqrt{f_p/E}\,L/d)$

If P is tension $\quad i = (f_a - f_p)/2\sqrt{Ef_p}\,\tanh(4\sqrt{f_p/E}\,L/d)$

Fig. 6, may be used to solve these by using $L/t = 1.155\ L/d$ and multiplying the angle obtained from the chart by 0.866.

The maximum angle of rotation for pivots such as are shown in Fig. 3 can be obtained in a similar manner. In this case the maximum bending moment occurs at the center of the flexure when the load is compression, and at the ends when the load is tension. The value of the maximum is given below.

If P is zero $\quad M/i = EI/L$

If P is compression $\quad M/i = (\sqrt{EIP}/2)\ \csc(\sqrt{P/EI}\ L/2)$

If P is tension $\quad M/i = (\sqrt{EIP}/2)\coth(\sqrt{P/EI}\ L/2)$

From these the values of i used to plot the curves on Fig. 8 are obtained,

If P is zero $\quad i = 2(L/t)(f_a/E)$

If P is compression $\quad i = (f_a - f_p)(2/\sqrt{3Ef_p})\sin(\sqrt{3f_p/E}\ L/t)$

If P is tension $\quad i = (f_a - f_p)(2\sqrt{3Ef_p})\tanh(\sqrt{3f_p/E}\ L/t)$

A comparison of Figs. 7 and 8 shows that the maximum angle is the same for both types of pivots when no load is applied, but when load is applied the fixed center type, shown in Fig. 8, may be rotated farther. This difference is quite pronounced when the flexures are long and slender.

Design Procedure

Pivots may be designed to suit so many different requirements that no procedure is suitable for every case. Suppose it is desired to design a pivot of the simple type shown in Fig. 2, which will support 500 lbs. either in compression or in tension, and which may be rotated three degrees to either side of its neutral position without exceeding a stress of 100,000 lbs. per sq.in. If a suitable value of L/t can be selected, the pivot dimensions can be determined from Figs. 5 and 7. From the latter chart it can be seen that L/t cannot be much less than 8 if the pivot is to be rotated three degrees. Also it will be seen that if L/t is 12, 16, or 20, larger values of f_p may be used, and this results in smaller cross-section and therefore smaller restoring moment. Referring to Fig. 5, it is seen that the stiffness per unit volume is much less if L/t is 20 than if L/t is 12. The actual stiffness is not so much less, because the pivot volume increases with L/t. For most purposes it would be best to use a lower value than that permitting maximum f_p because such a flexure lends itself to more accurate compensation for stiffness, and because it has greater rigidity parallel to the applied load. The latter reason becomes important when a series of flexure pivots support a load so that their deflections are additive. If L/t is 12, Fig. 7 shows that f_p can be about 17,000 lbs. per sq.in. tension and still permit three degrees rotation, and that the compression stress can be somewhat higher. Therefore to support 500 lbs., the area must be 500/17,000 = 0.0294 sq.in. By using a very wide flexure this area can be obtained with an extremely thin section, thereby making the stiffness almost negligible. Unfortunately construction difficulties require that the thickness be at least several thousandths of an inch. Moreover the width is often limited by available space. If this flexure can be two inches wide, its thickness will be 0.0147 in., and its length will be 12 × 0.0147 = 0.1764 in., and its volume will be 0.0294 × 0.1764 = 0.00519 cu.in. The stiffness per unit volume as obtained from Fig. 5 is about 22,000 at 17,000 lbs. per sq.in. tension, and 12,000 at the same compression stress. Multiplying by the volume, gives for the actual stiffness, 114 when the full 500 lbs. tension is applied, and 62.2 when the same amount of compression is applied. The restoring moment for three degrees rotation is obtained by multiplying by 3/57.3, giving roughly 6 in. lb. and 3.5 in. lb., respectively.

If the width of this flexure had been limited to one inch instead of two inches, the restoring moment would have been just twice the above values. A better understanding of effect of the several variables can be obtained by the studying of the following expression for the stiffness when no load is applied; $M/i = EP^2/12\,bf_p^2(L/t)$, in which b is the width of the flexure.

Because of its fixed center of rotation and its great lateral rigidity, the pivot shown in Fig. 3 is much more desirable for the fulcrum of a beam than a single flexure. The selection of the dimensions of the separate flexures can be made in much the same manner as has been suggested for the simple type, but Figs. 6 and 8 must be used, and the load on each flexure will be 1.414 times $P/4$, in which P is the load on the entire pivot, tending to press the two blocks together or pull them apart.

Method of Construction

The flexure pivots shown in the photographs were machined from steel bars leaving the flexures considerably oversize until after heat treatment. The heat treatment was chosen so that the steel used would have a yield point slightly more than 120,000 lbs. per sq.in. In this condition the steel could be machined satisfactorily to the desired final dimensions. A sup-

porting block was inserted when making the final cut, to avoid bending the thin sections. To reduce concentration of stress at the ends of the flexures, fillets were provided with radii approximately equal to the thickness of the flexure. Tests indicate that about 60 percent of these fillets should be included in determining the length to be used in theoretical analysis.

The first set of "Z" pivots were made without regard to the direction of the grain of the steel. A test performed on them showed that a noticeable permanent set took place when the stress was much less than that reached in the single flexure pivots which were cut parallel to the grain. Therefore all the "Z" pivots had to be machined from the bar cornerwise with the flexure parallel to the grain. When finished these were pressed into the end blocks with suitable spacers between them to make the complete unit shown in Fig. 3. To avoid any torsional strain when load is applied, the two middle flexures slope in one direction and the two outside flexures slope in the opposite direction.

Choice of Material and Allowable Stress

There is a very slight hysteresis loss in all materials when they are subjected to a varying load. This loss increases rapidly as the stress increases, and therefore if high sensitivity is required, relatively low stress should be used. Since this necessitates a larger section area, it results in greater stiffness, but by resorting to accurate compensation the pivot can be given any desired sensitivity up to the limit fixed by the internal hysteresis of the material. An attempt to measure the effect of this energy loss failed, because the apparatus was not sensitive enough. Some idea of the magnitude of the loss can be obtained from Reference 4.

Published information seems to indicate that phosphor bronze has less internal hysteresis than any other well known material, and therefore it may be preferable for very sensitive pivots. Recently, the claim has been made that beryllium copper has even less internal hysteresis, and this combined with its remarkably high strength should make it particularly desirable. For ordinary purposes, steel is the most logical material to use. Although its composition and heat treatment may vary considerably, a high yield stress is desirable, but brittleness must be avoided and the cost of manufacture may require that the steel be not too hard to machine.

For most purposes it will be found satisfactory to design the pivots using an allowable stress a little more than one half the yield point. Those described here were designed using 80,000 lbs. per sq.in., which is about two-thirds of the yield point, but the normal operating load is not more than half the design load. Consequently, it is only on rare occasions that they will be loaded to more than one-third of the yield stress. In spite of this precaution, it is possible that initial strains existing in parts of the flexures may cause a slight permanent set when the load is applied for the first time, but after the pivots have been subjected to several alternations of load, this effect should vanish.

[4] A. L. Kimball and D. E. Lovell, *Internal Friction in Solids*, A.S.M.E. Transactions, Vol. 48, page 479, 1926. Also see, M. F. Sayre and Anthony Hoadley, *Stress Distribution and Hysteresis Losses in Springs*, A.S.M.E. Transactions, Vol. 51, page 287, 1929.

Book Review

Flying Vistas, by Dr. Isaac H. Jones; J. B. Lippincott Company, Philadelphia, 1937; 255 pages, $2.00.

Usually books written by physicians contain so many forbidding medical terms that the layman misses much of their meaning. Dr. Jones has avoided this characteristic and has even been successful in writing of physiology in a style that is both interesting and understandable by readers of all ages.

The book gives the impression of being the result of making notes over a period of many years and finally assembling them in chapters. Or perhaps he found out by giving addresses, what kept an audience interested and what questions were usually asked.

Dr. Jones' background of experience starts at the beginning of the study in the United States of medicine and physiology in their applications to aviation. With Colonel Lyster he pioneered, not only the study, but the organization of the medical service of the Air Corps. They developed a technique which now comprises the work done by the officers they called "Flight Surgeons."

While the book is primarily a discussion of the physical examinations a pilot has to undergo before he is allowed to fly, Dr. Jones has cleverly addressed the book to a general audience so that any person reading it will have a much clearer understanding of those parts of his body which must be in perfect condition to make it safe for him to fly, or if he does not fly he will receive new impressions of the functioning of the eyes and ears. Great stress is laid on the dual function of the ear.

A chapter that the air lines could reprint is titled "The Air Commuter—(Suggestions for Passengers)." Here, the questions that passengers usually ask are answered and an explanation given of many disturbing effects of flying on some persons.

The latter part of the book will be of value principally to those in the Air Corps who are interested in the history of aviation medicine and how it developed during the war. Bill Ocker, now Lieutenant Colonel Ocker, is correct when he writes that the book should have a wide appeal to the general public.

The Bearing Strength of Steel and Aluminum Alloy Sheet in Riveted or Bolted Joints

ROY A. MILLER, *Consolidated Aircraft Corporation*

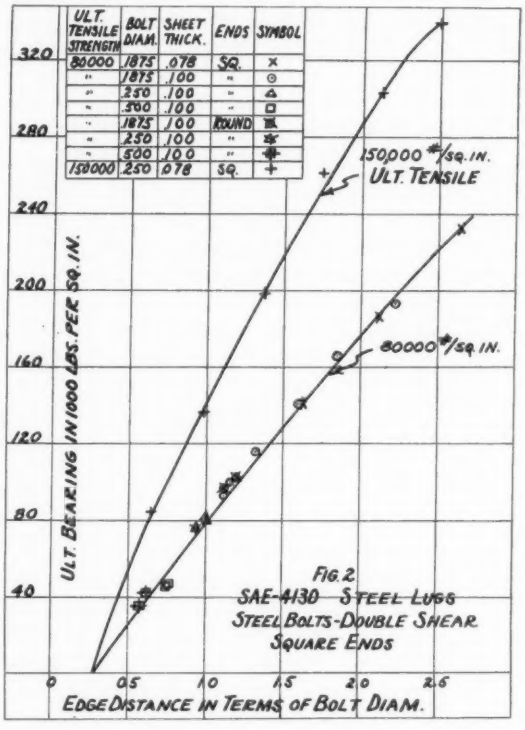
(Received July 6, 1937)

THE object of this investigation was to develop "tear-out" design criteria by means of which the strength of the material outside the bolt or rivet in a joint in tension could be more accurately determined. As test data were obtained and studied it became apparent that the edge distance had a definite relationship with the bearing strength and the test program accordingly was arranged to show how the bearing strength varies with the edge distance, with bolt or rivet size and with sheet thickness.

A number of typical test specimens are shown in Fig. 1. In all cases the specimen was made of two pieces of 24ST aluminum alloy or chrome-molybdenum steel sheet fastened together with a single bolt or rivet. The bolts were of steel heat-treated to an ultimate tensile strength of 125,000 lbs. per sq.in. and were used in all cases in double shear. The rivets were made from 17S aluminum-alloy rivet wire purchased under Army-Navy specifications and heat treated in a nitrate bath to an ultimate tensile strength of 55,000 lbs. per sq.in. They were used in all specimens in single shear. All specimens were tested in tension to failure.

Most of the specimens were formed with square ends. A few, however, were made with rounded ends. Of the latter specimens some had the bolt hole drilled concentric with the rounded end, some had the hole drilled with a plus offset and some with a minus offset, as noted in the presentation of the test results. To clarify the offset designations it may be stated that when the distance from the center of the hole to the end of the lug was less than the radius of curvature of the rounded end, the offset was assumed to be minus.

The sheet stock used in these tests was purchased under Army-Navy specifications. Test coupons were cut from the 24ST material and showed an ultimate tensile strength that varied from 68,100 to 73,700 and averaged 71,000 lbs. per sq.in. The bearing values obtained in the tests were not corrected to a common ultimate strength. In the case of the chrome-molybdenum steel specimens tested in the "as received" condition, the test coupons showed a variation in ultimate strength of 71,800 to 83,500 lbs. per sq.in. The



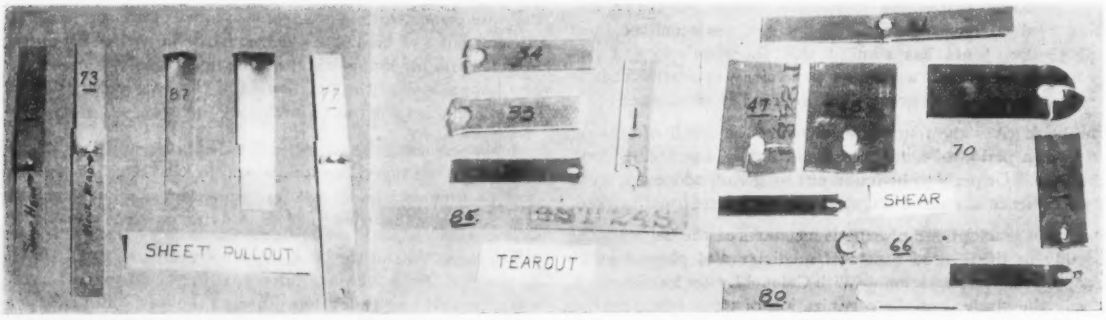
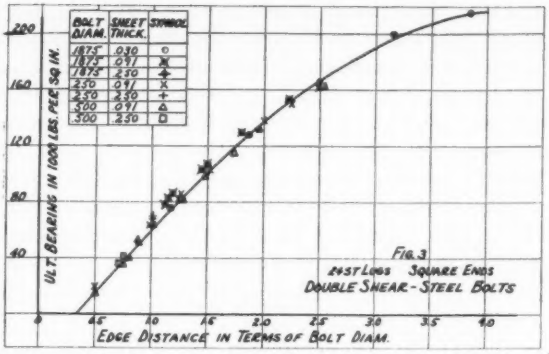
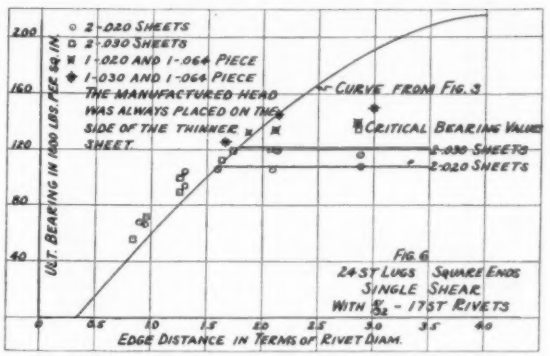
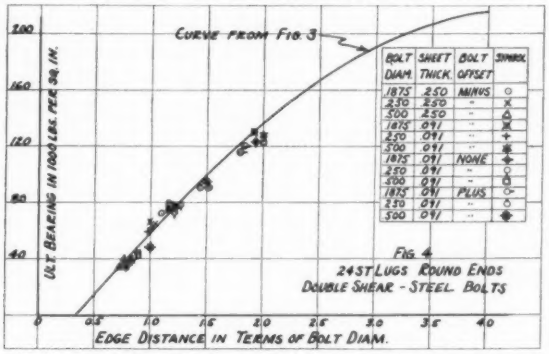
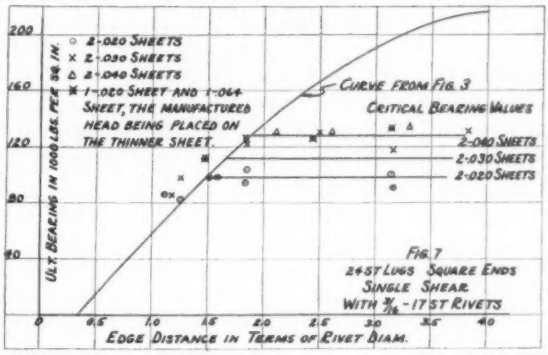


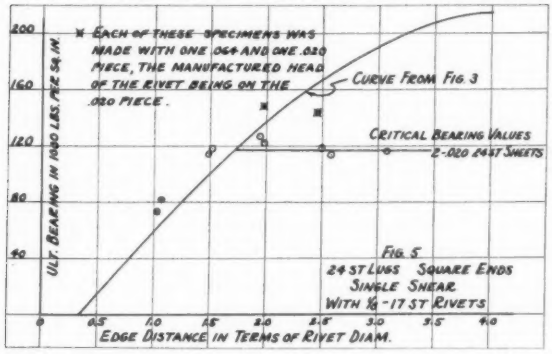
FIG. 1. Typical lug or seam failures.

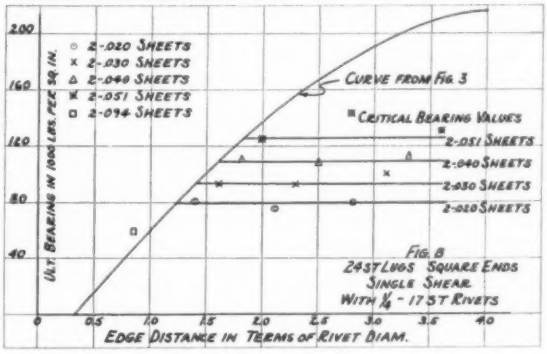

BOLT DIAM. | SHEET THICK. | SYMBOL
.1875 .030 ○
.1875 .091 ✕
.1875 .250 ◆
.250 .091 ✕
.250 .250 +
.500 .091 △
.500 .250 □
ULT. BEARING IN 1000 LBS. PER SQ. IN.
EDGE DISTANCE IN TERMS OF BOLT DIAM.
FIG. 3
24ST LUGS SQUARE ENDS
DOUBLE SHEAR - STEEL BOLTS


○ 2-.020 SHEETS
□ 2-.030 SHEETS
✕ 1-.020 AND 1-.064 PIECE
◆ 1-.030 AND 1-.064 PIECE
THE MANUFACTURED HEAD WAS ALWAYS PLACED ON THE SIDE OF THE THINNER SHEET.
CURVE FROM FIG. 3
CRITICAL BEARING VALUE
2-.030 SHEETS
2-.020 SHEETS
ULT. BEARING IN 1000 LBS. PER SQ. IN.
EDGE DISTANCE IN TERMS OF RIVET DIAM.
FIG. 6
24ST LUGS SQUARE ENDS
SINGLE SHEAR
WITH 5/32 - 17ST RIVETS


CURVE FROM FIG. 3
BOLT DIAM. | SHEET THICK. | BOLT OFFSET | SYMBOL
.1875 .250 MINUS ○
.250 .250 " ✕
.500 .250 " △
.1875 .091 " ✕
.250 .091 " +
.500 .091 " ✱
.1875 .091 NONE ◆
.250 .091 " ▽
.500 .091 " □
.1875 .091 PLUS ○
.250 .091 " △
.500 .091 " ◆
ULT. BEARING IN 1000 LBS. PER SQ. IN.
EDGE DISTANCE IN TERMS OF BOLT DIAM.
FIG. 4
24ST LUGS ROUND ENDS
DOUBLE SHEAR - STEEL BOLTS

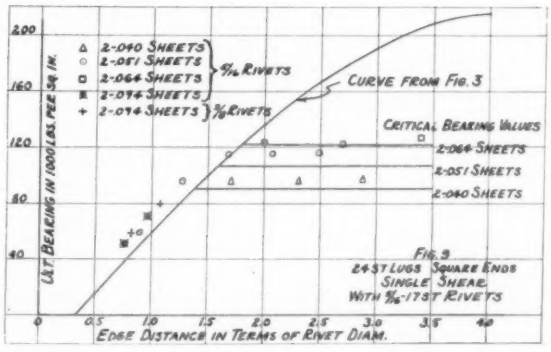

○ 2-.020 SHEETS
✕ 2-.030 SHEETS
△ 2-.040 SHEETS
✱ 1-.020 SHEET AND 1-.064 SHEET, THE MANUFACTURED HEAD BEING PLACED ON THE THINNER SHEET.
CURVE FROM FIG. 3
CRITICAL BEARING VALUES
2-.040 SHEETS
2-.030 SHEETS
2-.020 SHEETS
ULT. BEARING IN 1000 LBS. PER SQ. IN.
EDGE DISTANCE IN TERMS OF RIVET DIAM.
FIG. 7
24ST LUGS SQUARE ENDS
SINGLE SHEAR
WITH 5/32 - 17ST RIVETS

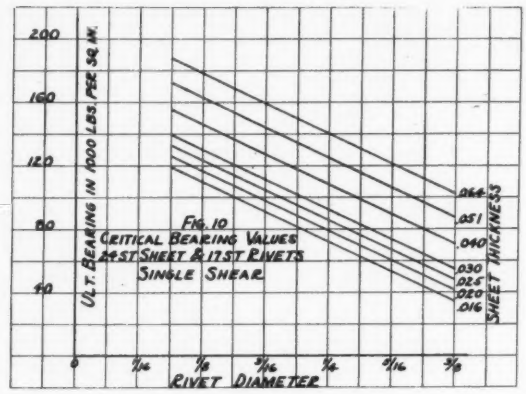

✱ EACH OF THESE SPECIMENS WAS MADE WITH ONE .064 AND ONE .020 PIECE, THE MANUFACTURED HEAD OF THE RIVET BEING ON THE .020 PIECE.
CURVE FROM FIG. 3
CRITICAL BEARING VALUES
2-.020 24ST SHEETS
ULT. BEARING IN 1000 LBS. PER SQ. IN.
EDGE DISTANCE IN TERMS OF RIVET DIAM.
FIG. 5
24ST LUGS SQUARE ENDS
SINGLE SHEAR
WITH 1/8 - 17ST RIVETS



bearing values obtained with these test specimens were corrected to a common ultimate strength of 80,000 lbs. per sq.in. by means of the assumption that the ultimate bearing strength varies directly as the ultimate tensile strength. In the case of the chrome-molybdenum steel specimens heat-treated to 150,000 lbs. per sq.in., the test coupons heat-treated with them, showed a variation in ultimate tensile strength between 146,500 and 151,000 lbs. per sq.in. The bearing values obtained from these test specimens were also corrected to a common ultimate strength of 150,000 lbs. per sq.in. as in the above instance.

The ultimate bearing strength used in plotting the test results is assumed to be the load at failure divided by the product of the sheet thickness and the bolt or rivet diameter. The sheet thickness was carefully measured in each case but the bolt or rivet diameter was assumed to be the nominal value. Ample material in all cases was provided beside the hole to eliminate the possibility of a tension failure and the rivet and bolt sizes were so selected that their shear strengths would not be critical. With the exception of a few of the stronger specimens, all tests were conducted in a 5000-lb. Olsen Hydraulic Testing Machine. The exceptions were tested in a Southwark-Emery Hydraulic Testing





Machine using the 20,000-lb. capacity dial. The specimens were made in the shop of Consolidated Aircraft Corp. with the same care afforded the regular production work and the tests were conducted in the Company's testing laboratory.

Test Results

For convenience the test results are plotted in groups in Figs. 2 to 9, inclusive. It will be noted that results were obtained over a wide range of bolt, rivet, and sheet sizes. In these figures the ultimate bearing stress intensities as ordinates are plotted in terms of the edge distance in bolt or rivet diameters, the "edge distance" being defined as the distance from the center of the bolt or rivet hole to the edge of the lug or joint. When plotted in this manner the results from the tests in double shear, Figs. 2 and 3, form a consistent smooth curve throughout the range of this investigation. The data from the test specimens in double shear and with rounded ends are plotted in Fig. 4 and are shown to follow very closely the curve obtained from similar double shear specimens but with squared ends. Rounding the ends of the lug appears to give slightly lower values but no consistent difference was noted between the concentric lugs and those with either minus or plus offsets of the bolt hole.

The ultimate bearing values for 24ST sheet and 17ST rivets in single shear plotted in Figs. 5 to 9, inclusive, show that these data follow the curve obtained for specimens in double shear as the edge distance increases until some critical value is reached, after which no increase in ultimate bearing stress is attained with further increases in edge distance. The critical values obtained from these curves are plotted in Fig. 10 in terms of rivet diameter and ultimate bearing stress intensity. This chart shows that the critical value depends upon the size of the rivet and the thickness of the sheet and, within the scope of this investigation, the relationship appears to be linear.

During this investigation it was noted that underdriven rivets resulted in lower bearing values and that rivets driven with greatly increased pressures gave increased ultimate bearing loads though the tendency in this latter case, as is to be expected, was to result in damage to the sheet immediately adjacent to the rivet. It was also noted, as shown in Figs. 5, 6, and 7, that when a joint in single shear was made with two pieces of sheet of different thickness, the strength in bearing was greatly improved if the manufactured head was placed on the side of the thinner sheet.

Conclusions

It is concluded that the bearing strength of a joint made of sheets in combination with bolts or rivets depends upon the material, the sheet thickness, the bolt or rivet size, and the edge distance. The ultimate bearing stress intensity does not appear to vary directly as the ultimate tensile strength of the material, though the error involved in making such an assumption is small for small differences. Curves by means of which the allowable ultimate bearing value for 24ST aluminum alloy sheet may be obtained are given. Similar curves are also given for chrome-molybdenum steel sheet in double shear and with ultimate tensile strengths of 80,000 and 150,000 lbs. per sq.in. No additional calculations need be made to determine the strength of the material outside the bolt or rivet (the tear-out value) if use is made of the bearing values shown in Figs. 2 to 10, inclusive.

Some Full Scale Static Propeller Characteristics[1]

LOUIS H. ENOS, *Wright Field*

(Received September 17, 1937)

Summary

IN ORDER to properly evaluate the effect of tip speed and profile shape upon the thrust to hp. ratio of a propeller, allowance must be made for torsional deflection of the blade if such occurs.

Under static conditions the effect of tip speed is greater at blade angles of 15° than at 23°. For a propeller using an R.A.F. 6 profile the tip-speed effect is noted above 700 ft. per sec., while for propellers using the Clark Y and N.A.C.A. 2400 profiles the effect becomes noticeable above 900 ft. per sec., particularly for the lower blade angles.

For a value of C_P of 0.06, equivalent to a blade angle of approximately 15°, and a tip speed of 900 ft. per sec., the R.A.F. 6 profile propeller gives a C_T/C_P ratio 4.5 percent greater than the Clark Y and 6.5 percent greater than the N.A.C.A. 2400 profile propeller. At a C_P of 0.12, equivalent to a blade angle of approximately 23°, the values are, respectively, 10.5 and 15.0 percent greater.

The ratio of the net static thrust on a single-engined airplane to the propeller-shaft thrust varied from 0.85 on a high-wing monoplane with several struts in the slip stream to 0.95 on a streamlined low-wing monoplane.

Introduction

With the present-day large airplane, the take-off conditions largely influence the selection of the propeller. Data covering the operating characteristics of full scale propellers operating at full power in the take-off range are very limited. The amount of over-revving at take-off that can be used without appreciably reducing the thrust due to tip-speed effect and the most satisfactory blade angles to use are matters of importance in selecting a propeller for a given airplane. While the data here presented have been determined statically the characteristics give a basis for estimating the thrust during the take-off run since with constant-speed propellers the thrust does not vary appreciably in this range for values of C_P normally used.[2,3]

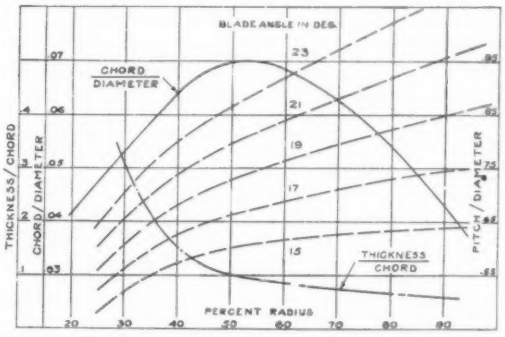


FIG. 1. Planform, camber ratio, and pitch diameter ratio.

Description of Propellers and Tests

The data presented were obtained from tests made on the electrically driven whirl test stand at Wright Field. All thrust and power values were measured on the propeller shaft. Three constant-speed, three-bladed, aluminum alloy, 10-ft. diameter propellers were used. They were geometrically similar in planform, camber ratio, and pitch distribution and differed only in blade profile. The nominal rating for the propellers is approximately 800 hp. while the tests covered a range of from 300 to 1500 hp. The blade-angle range was from 15° to 23°, since this blade-angle range covers angles usually used for take-off. All blade angles are for the 0.75 radius. The tip speed was run up to 1050 ft. per sec. Fig. 1 gives the planform, camber ratio, and pitch distribution for the three propellers. The R.A.F. 6 and Clark Y profiles are those commonly used for propellers which are slightly modified from the true profile. The N.A.C.A. 2400 profile is the basic profile with the chord reduced slightly and a trailing edge radius introduced. All data are given for standard atmosphere at sea level.

Determination of Propeller Characteristics

The relationship between the factors affecting the hp. absorbed and the thrust developed by a propeller is usually expressed by the equations:

$$\text{hp.} = C_P \cdot \rho \cdot n^3 \cdot D^5/550 \qquad (1)$$

$$\text{Thrust (lb.)} = C_T \cdot \rho \cdot n^2 \cdot D^4 \qquad (2)$$

[1] This article is based upon Air Corps Technical Report No. 4319 (Unrestricted Status), titled: *Static Thrust Characteristics of Propellers Using Clark Y, R.A.F. 6, and 2400 Profiles*, by Louis H. Enos, June 25, 1937.

[2] Th. Theodorsen, G. W. Stickle, and M. J. Brevoort, *Characteristics of Six Propellers Including the High Speed Range*, N.A.C.A. Technical Report No. 594, September, 1936. (See Figs. 45 and 46.)

[3] F. W. Caldwell, E. Martin, and T. B. Rhines, *The Constant Speed Propeller*, S.A.E. Journal, Vol. 40, No. 1, page 30, January, 1937.

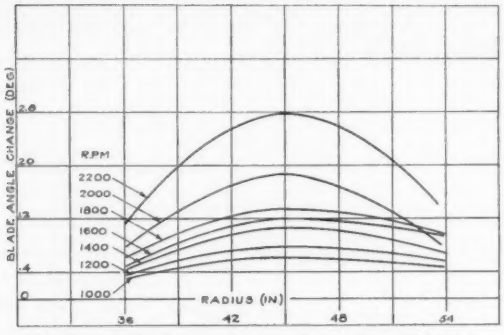


FIG. 2. Angle change *versus* radius. Clark Y blade.

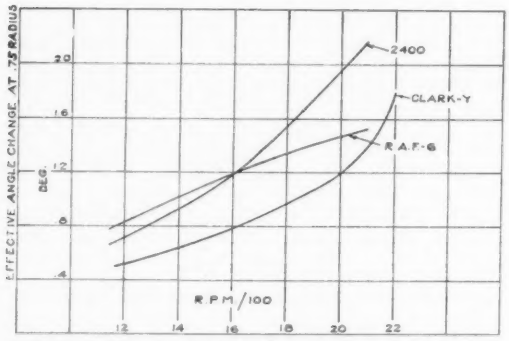


FIG. 3. Effective blade-angle change at .75 radius.

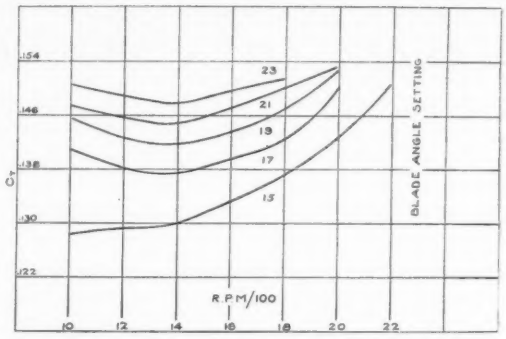


FIG. 4. C_T *versus* r.p.m. and angle setting. Clark Y blade.

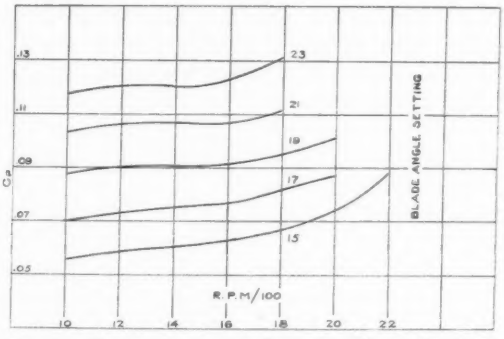


FIG. 5. C_P *versus* r.p.m. and angle setting. Clark Y blade.

where,

ρ = air mass density
n = r.p.s.
D = propeller diameter in ft.
C_T = thrust coefficient
C_P = power coefficient

The relationship of the thrust and power coefficients to a propeller is similar to the relationship of the lift and drag coefficients to a wing. For a wing of given planform, camber ratio, and profile the lift and drag coefficients vary with the angle of attack and the air speed. For a given propeller the thrust and power coefficients vary with the blade angle and relative air speed. It is therefore obvious that it is just as necessary in determining propeller characteristics to evaluate the blade-angle change due to distortion under load as it would be in the case of a wing test where distortion of the model occurred.

Where changes in design are being incorporated, such as a change of profile, or where the tip-speed effect is desired, the variation in the thrust and power coefficients due to angle change may be as large as the effect due to the design change or tip-speed effect. In general, this factor of blade-angle change has not been evaluated in propeller test data and the entire variation in the characteristics has been charged to the design change or tip-speed effect.[4] Necessarily some variation is due to change in Reynolds Number with change in r.p.m., and this change, which is small, is charged to tip speed.

Blade-Angle Change

Blade-angle changes were measured with a special instrument employing a surveyor's level and a prism which can be moved parallel and at right angles to the plane of rotation of the propeller. The amount of movement is measured upon a calibrated scale incorporating a vernier. By noting the changes in the location of the leading and trailing edges of the blade at a given radius as the operating conditions change, the transverse and angular deflections can be calculated. This method has been in common use for some time although it loses accuracy rapidly when flutter or other severe vibration of the blades occurs. Figs. 2 and 3 show the blade-angle change measured. Fig. 2 gives the change in angle along the blade with change in r.p.m. for the Clark Y profile, while Fig. 3 is a mean value of the angle change at 0.75 radius representing the effective change for the entire blade. It was observed during the tests that the blade-angle change varied with r.p.m. but was not dependent upon the blade-angle setting. This characteristic is observed on other propellers operating under static conditions.

Thrust and Power Coefficients

Thrust and power coefficients are calculated from measured thrust and hp. readings. The values for the Clark Y profile are given in Figs. 4 and 5 plotted against

[4] Donald H. Wood, *Full Scale Tests of Metal Propellers at High Tip Speeds*, N.A.C.A. Technical Report No. 375, 1931. (See page 9.)

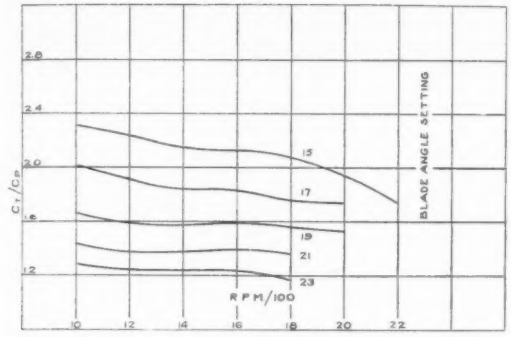


FIG. 6. C_T/C_P *versus* r.p.m. and angle setting. Clark Y blade.

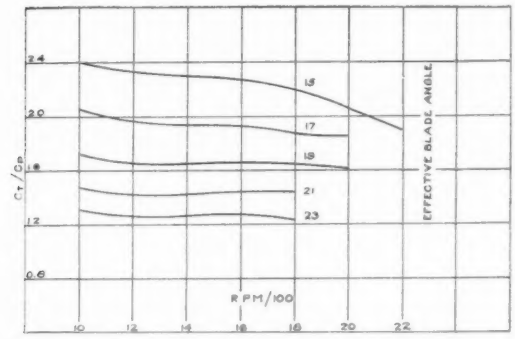


FIG. 7. C_T/C_P *versus* r.p.m. and effective angle. Clark Y blade.

r.p.m. for blade angles from 15° to 23°. Fig. 6 gives the C_T/C_P ratio over the same range. Since C_T/C_P varies with the blade-angle change this ratio was cross-plotted against blade angle and then corrected to the effective angle from the values given in Fig. 3. Fig. 7 gives the corrected C_T/C_P ratio for the effective blade angles. The relative merit of the three profiles when operating at a tip speed of 900 ft. per sec. is shown in Fig. 8. It will be noted that the N.A.C.A. 2400 profile is relatively unsatisfactory under static conditions at this tip speed for the range of angles tested.

EFFECT OF TIP SPEED

From Eqs. (1) and (2) it can be seen that

$$\text{Thrust} = \frac{C_T}{C_P} \times \frac{\text{hp.} \times 550}{nD} \qquad (3)$$

which indicates that so long as the ratio C_T/C_P remains constant, the thrust varies directly as the hp. and inversely as the tip speed.[5] At the higher tip speed, however, the ratio C_T/C_P may vary as shown by the slope of the C_T/C_P *versus* r.p.m. lines in Fig. 7. In Fig. 9 the tip speed of 900 ft. per sec. has been taken as the basis of comparison as this tip speed is an average for a number of propeller installations. The curves show the variation in the C_T/C_P ratio for variations from this tip speed. For all three profiles the tip-speed

[5] Walter S. Diehl, *Static Thrust of Airplane Propellers*, N.A.C.A. Technical Report No. 447, 1932.

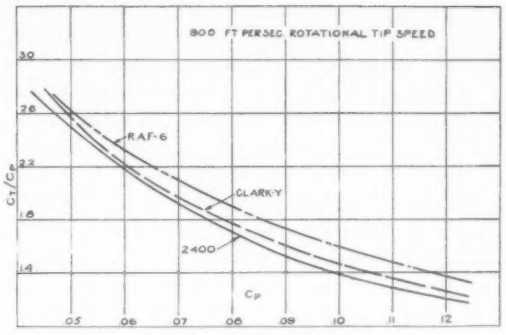


FIG. 8. C_T/C_P *versus* C_P.

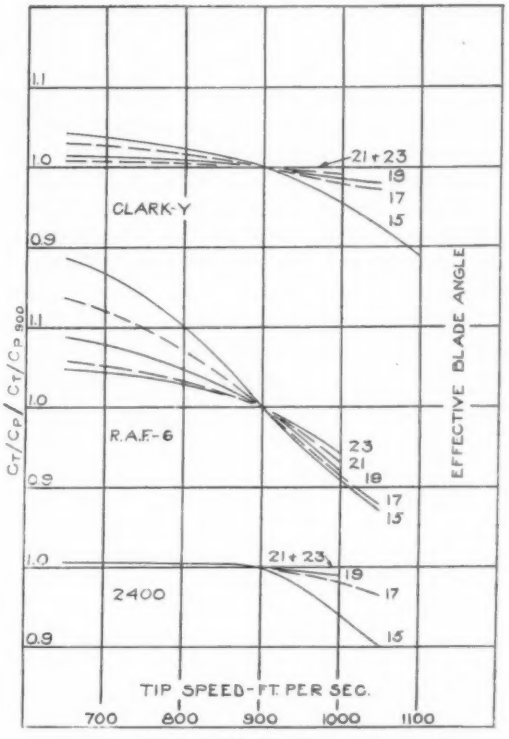


FIG. 9. $(C_T/C_P)/(C_T/C_{P900})$ *versus* tip speed.

effect is greater for the low angles and the R.A.F. 6 profile is much more critical to tip-speed effect than are the other two. The N.A.C.A. 2400 profile may offer some advantages on installations where tip speeds ran over 1050 ft. per sec. The R.A.F. 6 profile due to its critical tip-speed characteristics will decrease the possible gain in thrust due to increased power when overrevving as the tip speed goes up. If, however, the take-off condition is critical and large diameters not possible, this profile will help maintain the thrust on propellers of smaller diameter and four or six blades operating at low tip speeds.

NET STATIC THRUST AND POWER ON AIRPLANE

Since the data given is for shaft thrust and power, it is desirable to know the variation in these values when

the propeller is installed on an airplane. It has been the practice at Wright Field for a number of years to determine the power absorbed at various blade angles and r.p.m. on the electric whirl test stand and to assume these values apply for the same propeller when installed on an airplane. This assumption is justified since it has been found that the blade-angle change necessary to bring an engine up to its rated r.p.m. at rated carburetor air temperature and manifold pressure is generally less than one-half degree. In terms of hp. this means within 2 to 3 percent of the rated power. This variation in power is small when it is realized that the same variation may occur between two new engines or during the time between overhauls on one engine. In the near future when a shaft thrust and torque dynamometer, now under construction for Wright Field, is available, this assumption can be accurately checked.

The net accelerating thrust, rather than the shaft thrust, is the important factor on the airplane during take-off. In order to determine the variation between the shaft thrust measured on the whirl test stand and the net thrust on the airplane, the net static thrust on an observation type, high-wing, single-engine monoplane was measured. The propeller with the Clark Y profile was used. Fig. 10 gives the relative values of C_T/C_P for a given C_P and tip speed for the whirl test stand and airplane. The drag due to the airplane rolling friction, which will vary with the airplane weight,

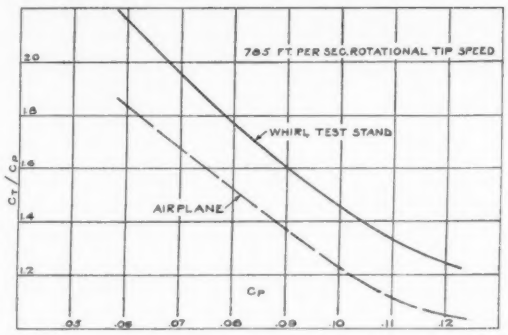


FIG. 10. C_T/C_P *versus* C_P. Clark Y blade on whirl test stand and airplane.

is not included in the net static thrust values given. For a tip speed of 785 ft. per sec. the ratio of the net static thrust on the airplane to the shaft static thrust on the stand varied from 0.85 to 0.88. On a more streamlined ship or on a wing nacelle the ratio would be higher. A series of tests on two low-wing, single-engine airplanes with different propellers gave ratios of from 0.90 to 0.95.

A high-speed test of the observation type airplane with the three propellers gave maximum speeds within 2 m.p.h. of each other. Since this variation is within the accuracy of the air-speed indicator used, it is apparent that the efficiency of the three propellers at high speed is practically the same.

Institute Notes

First Wright Brothers' Lecture and Annual Dinner of Institute

The first Wright Brothers' Lecture will be given by Professor B. Melvill Jones on the afternoon of December 17. The subject will be "Boundary Layer Experiments in Flight." In the evening at the Hotel Biltmore, the Annual Dinner of the Institute will be held. At the dinner, at which Professor Jones will be the guest of honor, The Daniel Guggenheim Medal, The Sylvanus Albert Reed Award, The Lawrence Sperry Award and other honors will be presented.

Branches Formed

The first meetings of Branches of the Institute were held on October 15, in New York, Los Angeles, Philadelphia, and Washington, where applications for Branch Charters were signed and the preliminary action taken for the organization of Branches. Several other cities are also planning to start Branches, but were not able to hold meetings on October 15, the Fifth Anniversary of the incorporation of the Institute.

A Correction

The notice in the October issue of the Journal regarding the meeting in September, 1938 of the Fifth International Congress for Applied Mechanics unfortunately omitted to mention that Harvard University together with the Massachusetts Institute of Technology will act as joint hosts to the Congress. The meeting of this Congress in the United States is in consequence of a joint letter of invitation from Presidents Conant and Compton, presented to the Fourth Congress at its meeting at Cambridge University in 1934.

Course in Celestial Navigation

A course in Celestial Navigation will be given cooperatively by the Hayden Planetarium of The American Museum of Natural History, the Division of General Education of New York University, and Lieutenant Commander P. V. H. Weems, once weekly for sixteen weeks beginning November 3. The course, which will cover such topics as the use of the Nautical Almanac, the marine sextant, bubble sextant, graphical methods, star altitude curves, etc., is intended for navigators and aviators who wish to extend their knowledge of celestial navigation. The course will be under the direction of Lieutenant Commander Weems, originator of the Weems system of navigation, who, with the assistance of other outstanding authorities, will conduct the classes. Students will have opportunities to make actual observations, computations, and to use instruments.

Personal Notes

The appointment of Herbert V. Thaden, an Associate Fellow of the Institute, as sales engineer in the Stainless Steel Division of the Carnegie-Illinois Steel Corporation of Pittsburgh, Pa., was announced by the Carnegie-Illinois Steel Corporation last month. Mr. Thaden will devote his efforts to the technical and business development of stainless steel products for aircraft use.

Meetings

December 17, 1937. The Wright Brothers Lecture by Professor B. Melvill Jones of Cambridge University, England. Annual Dinner and Honors Night. Conferring of Honorary Fellowships, presentation of Daniel Guggenheim Medal, Sylvanus Albert Reed Award, and Lawrence Sperry Award. Hotel Biltmore, New York.

December 21, 1937. Wright Brothers Lecture repeated by Professor B. Melvill Jones at the California Institute of Technology, Pasadena, California.

December 27–30, 1937. Institute Meeting as part of Annual Meeting of the American Association for the Advancement of Science, Indianapolis, Indiana.

January 24–26, 1938. Annual Technical Meeting of the Institute of the Aeronautical Sciences, Columbia University, New York.

February 11, 1938. Institute of the Aeronautical Sciences Los Angeles Branch Annual Meeting Review, Los Angeles, California.

June 28–30, 1938. Institute Meeting as part of Summer Meeting of the American Association for the Advancement of Science, Ottawa, Canada.

September 12–16, 1938. International Congress for Applied Mechanics, Massachusetts Institute of Technology and Harvard University, Cambridge, Massachusetts.

Airport Inspection Trip

The Secretary of the Institute, Major Gardner, was one of a party headed by Corrington Gill, Assistant Federal Administrator of the Works Progress Administration, to make an inspection trip to airports from Washington to the Pacific Coast. The W.P.A. has provided $75,000,000 for the development of airports in the United States and the trip was to study the progress that had been made and to consider future requirements.

Visitors to the Institute

Recent visitors to the Institute have been H.R.H. Archduke Franz Josef of Vienna, Austria; H. Sternberg, Royal Netherlands Aero Club, Amsterdam, Holland; J. D. North, Boulton & Paul Aircraft, Ltd., Wolverhampton, England.

Necrology

Balz Zimmerman, Director of "Swissair," the Swiss Air Transport Company, and an Associate Fellow of the Institute, died at Zurich in October. He was born in 1895, and studied mathematics and physics at the Federal Polytechnic at Zurich. During the War he entered the Swiss Frontier Service and soon became interested in aviation. In 1926, he left the Service to become Director of the newly founded air traffic company "Balair," at Basle. Together with his friend, Walter Mittelholzer, head of the "Ad Astra" in Zurich, he realized the need of a united Swiss company for international air service, and, in 1931, the two companies were amalgamated to form "Swissair." Balz Zimmerman was a pioneer of high-speed air traffic in Europe and was the first to introduce the Lockheed "Orion" high-speed airplanes; he was among the first who continuously made great efforts for the acceleration of the European routes.

AERONAUTICAL REVIEWS

These brief reviews of recent articles on aviation subjects are published by the Army Air Corps for the information of its officers, and are printed here each month by permission of the Chief of the Air Corps.

Aerodynamics

American Aviation. R. Boname and M. Jan-Kerguistel. Several pages are devoted to comments of these French engineers regarding equipment observed and research being carried on at Wright Field, and referring particularly to instruments, Link trainers, engine tests, aerodynamics, and radio equipment.

The article discusses in great detail the following: equipment and research of the N.A.C.A., New York University, and M.I.T.; research into problems of operation and of flight at high altitudes; the airplane of the future; materials; and relations of manufacturer to client in air transport contracts, and the suppression of the prototype phase. Continued. L'Aéronautique, June, 1937, pages 130–140 and 141–147, 20 illus.

Application of the Aerodynamic Balance at Chalais-Meudon to the Study of a Yawed Wing Model. M. P. Rebuffet. Principle of the aerodynamic balance used in the wind tunnel, a special mounting made for these tests, and results of tests on a yawed airfoil are described. Reference is made to the results obtained by Budig with a boat propelled by flapping blades. La Technique Aéronautique No. 144, 1937, pages 118–133, 13 illus., 5 tables, many equations.

Aircraft Design

Taxying-Bumps. Extra loads thrown on to the aircraft undercarriage as a result of upward acceleration caused by bumps in taxying. Formulas are developed for taxying loads in the case of long-distance record-breaking airplanes as well as for ordinary aircraft. Flight, Aircraft Engr. Sup., July 29, 1937, pages 4–5, 2 illus., many equations.

Theoretical and Experimental Fundamentals for Investigation and Development of Airplane Shock Absorbers. F. Michael. Investigation to establish a basis for the numerical evaluation of the quality of airplane shock absorbers. Idealized main-load cases, theory, properties, and the landing and rolling impacts are considered for the single shock absorber, and properties of the double shock absorber are taken up. Test methods for determination of shock-absorber properties are compared. Long detailed discussion. DVL report. Luftfahrtforschung, August 20, 1937, pages 387–416, 39 illus., 11 tables, 6 equations.

Aircraft Performance Estimation. C. O. Vernon. Methods by which performance is estimated for a new design. Lift and drag characteristics, propeller characteristics, level speed and climb, range, and take-off run are calculated. Jour. Royal Aeronautical Soc., August, 1937, pages 679–702, 21 illus., 63 equations.

Critical Speeds of Monoplanes. J. Hanson. Loss of lateral control at high speeds due to twisting of the wing, and the present position in regard to divergence and flutter. The discussion covers: wing stiffness; flexural center of a wing section; torsional stiffness; reasons for the use of the semi-rigid wing, its properties and success; problem of critical reversal speeds, their accurate and approximate solutions analytically, their experimental determination, and influence of torsional stiffness, wing plan form, aileron span and chord, skewed ailerons, and balanced ailerons; relation between critical reversal speed and maximum speed; alternative prevention of loss of lateral control; accurate and approximate analytical determination of divergence speed, factors influencing this speed, and relation between this speed and reversal speeds; and analytical determination of critical flutter speed and factors influencing it. Jour. Royal Aeronautical Soc., August, 1937, pages 702–726, 31 illus., 22 equations.

The Gyroplane. L. Bréguet. Advantages of the gyroplane in military and civil aviation, the efficiency of this method of flight suitably carried out by a proper inclination forward of the rotor axis, and the question of whether this efficiency and speed obtainable would be comparable with those of modern aircraft are considered. The discussion covers: difference between the gyroplane and autogiro; theory of the gyroplane and formulas for calculating its performance; forward speed at which the resulting speed at the extremity of an advancing blade does not reach the speed of sound; why the flapping movements even at high forward speeds, have very little detrimental effect on the lift/drag ratio; fundamental phenomena on which the theory of flapping is based; and the gyroplane of the future. Translated from Journées Techniques Internationales de l'Aéronautique, 1936. Jour. Royal Aeronautical Soc., September, 1937, pages 790–826, 23 illus., 35 equations.

A Method for Calculating the Performance of Airplanes. M. Nénadovitch. Method described for the calculation of airplane performance requires only one curve for the study of horizontal flight at different altitudes. The study of climb is also simplified, and only one curve is constructed to answer all the questions. La Technique Aéronautique No. 144, 1937, pages 134–150, 9 illus., 5 tables, many equations.

Stress Analysis and Structures

Stressed-Skin Construction. W. Tye. Distribution of loads on stringers and transverse rings in a monocoque fuselage. Results are given mainly in graphical form for a range of elliptical sections and include the effects of "direct" shear and shear due to torsion. The general expression for load distribution may be applied to fuselages of any section. Author is on the staff of the Royal Aircraft Establishment. Flight, Aircraft Engr. Sup., August 26, 1937, pages 7–11, 9 illus., many equations.

Towards Thermoplastics. Deekay wooden wing designed by S. C. Hart-Still and successfully tested at the Royal Aircraft Establishment. Wing consists of four main spars, three-ply covering and half a dozen ribs. Translated into plastic construction, the wing will have three spars with their booms reinforced with metal tube liners and the skin attached to the spars via molded-in metal strips and screws. Use is made of a bulbous section for the spars. Description of new construction. Flight, July 22, 1937, page 100, 7 illus.

Acceleration of Fatigue Tests. R. A. Hudson and J. E. Chick. The described method of producing vibrations in structures was developed by Goodyear-Zeppelin Corporation in connection with an investigation of the effects on the structure of various types of vibrations. An oscillatory mechanical system, and the oscillation inducing coil are described. Aero Digest, September, 1937, pages 78, 121, 5 illus.

The British Association. "The Analysis of Elastic Structure by the Methods of Deformation Energy and Remainder Distribution," E. H. Bateman. Brief abstract of paper presented at the Nottingham meeting and discussion by R. V. Southwell and others. Engineer, September 10, 1937, pages 286–287. Engineering, September 10, 1937, pages 289–290.

Section Constants. H. Parkinson. Method of approximating the radius of gyration of thin-walled sections. Aircraft Engineering, September, 1937, pages 241–242, 2 illus., many equations.

Shear in Tapered Box Girders. F. Nagel. Shear distribution formulas for box girders published in various articles do not consider the change of cross section along the span. Formulas for a tapered box girder are outlined and compared with those for a box girder without taper. Aero Digest, September, 1937, page 80, 1 illus., 1 table, 4 equations.

Aircraft

Aircraft in the Marseilles-Damascus-Paris Race. Amiot 370 (two Hispano-Suiza Y 860-hp. engines, estimated speed 295 m.p.h.), the Bellanca (Fairchild Ranger inverted-vee-twelve engine in the nose, two Menasco Buccaneer engines in wing nacelles, estimated top speed 270 m.p.h.), and the Couzinet monoplane (two direct-drive radial engines, estimated top speed 250 m.p.h.). Very few details of airplanes which were expected to participate in the race. Flight, August 12, 1937, page 164d, 4 illus.

The revised Comet, Britain's lone challenger in the Damascus Race, the Couzinet 10 (Hispano-built Wright Cyclones), the Bloch 160 (four 690-hp. Hispano-Suiza 12X medium-supercharged engines, recorded maximum speed, 220 m.p.h. at 9180 ft.), and the formidable Savoia Marchetti S.79s (267 m.p.h. maximum speed claimed). Few details of planes entered in the Race. Flight, August 19, 1937, pages 183–185, 5 illus.

Race was won by Italy at 219 m.p.h. First, second, and third places were taken by airplanes of the Savoia-Marchetti S.79 type fitted with three Alfa Romeo 126 R.C.34 radial aircooled engines of 750 hp. each. Account of the Race and photographs of the following: Fiat BR 20 As (adaptation of the bomber type), the Breguet Fulgur (averaging 182 m.p.h.), the Bloch 160 (four Hispano Series X 720-hp. engines), and the Farman.

Editorial comments on results of the Marseilles-Damascus air race. One considers the extent to which a tail wind must have helped and estimates speeds of the winning planes. Flight, August 26, 1937, pages 204–207, 203, 7 illus., 1 table.

The Fourth International Aircraft Meeting at Zurich. G. W. Feuchter. Account of the meeting with special consideration to the events for military aircraft. Photographs of the Dewoitine 510, Avia B 534, Fiat CR-32, and the Bf 109 (D.B.600 engine of 950 hp.) single-seater pursuits are included. The Alpine air tour held in connection with the meeting is described by Major Seidemann. Luftwehr, September, 1937, pages 349–355, 8 illus.

Account of the meeting and demonstrations by French and Italian military pilots. The Dornier Do.17 bomber and the new Heinkel fighter are illustrated in the second issue. Flight, July 29 and August 5, 1937, pages 114–116 and 142–143, 9 illus.

The Hague Show. Fokker's D-1 monoplane fighter (Mercury VII 840-hp. engines, estimated speed 278 m.p.h.), adopted as standard by Holland, Denmark, and Finalnd, a model of the Do.19 bomber (four 700/1000-hp. Brama engines), and a model of the Junkers Ju. 90 (four B.M.W. 132 H 820-hp. engines.). Very few details of these airplanes and of commercial aircraft exhibited. Flight, August 5, 1937, pages 139–141, 8 illus.

Canada

Out in the Cold, Cold Snow. A Special Hart with Perseus sleeve-valve engine, skis and cockpit enclosure on test with the Royal Canadian Air Force. Photograph only. Flight, July 29, 1937, page 119, 1 illus.

Czechoslovakia

The Prague Aero Show. Avia 35 single-seater fighter monoplane (1000-hp. engine, speed of 310 m.p.h.), Praga E.45 single-seater fighter biplane (600-hp. Rolls-Royce Kestrel VI engine), and the Avia 34 (650-hp. Hispano-Suiza engine). These military airplanes are mentioned and few details given of the small private airplanes exhibited as well as of the Walter Mikron II 62-hp. and the new direct-drive Praga D flat four 80-hp. engines. Flight, July 15, 1937, pages 76a–76b, 4 illus.

Zlin XIII, Praga E-115, and other sport airplanes. Few details and brief reference to the Avia 35 single-seater pursuit. Aviation, September, 1937, pages 54–55, 1 illus.

France

Air France's Fastest. Bloch 220 16-passenger high-speed twin-engined monoplane has a speed of 219 m.p.h. with two medium supercharged Gnôme Rhône 14-cylinder 880-hp. two-row radials at full throttle. Few details. Flight, July 29, 1937, page 122, 1 illus.

Airplanes in Test. Lioré-Olivier LeO-45 bomber (two Hispano-Suiza 14-AA 1150-hp. engines) with a 500-kg. bomb load can climb to 4000 meters in 11 minutes. Maximum speed is 420 km./hr. and range 2000 km. at an average cruising speed of 375 km./hr. The Caudron-Renault "Kangourou" 10-ton troop transport (two Renault 700-hp. engines) has a maximum speed of 276 km./hr. at 1500 meters and range of 1000 km. at 230 km./hr. cruising speed. Very brief notes on these French military airplanes in test, as well as notes on commercial and sport airplanes undergoing tests. Les Ailes, September 9, 1937, page 15.

French Air Force Display at Villacoublay. Account of the demonstration of French military aircraft with references to the following: The Dewoitine D.501, Morane 225 and Caudron-Renault C.710 single-seater pursuits, the LeO. O.C.30 gyroplane, and the Bloch 131 heavy bomber. Luftwehr, September, 1937, pages 355–358, 7 illus.

Brief account of demonstration. Flight, July 29, 1937, page 132, 1 illus.

The Four Winds. First of the big Farman 224s, fitted with four 800-hp. Gnôme-Rhône engines has completed its handling trials. A series has been ordered by Air France. Brief reference. Flight, August 19, 1937, page 181.

With Foreign Builders. New Lioré-Olivier LeO-47 40-passenger flying boat to be used by Air France for spanning the North Atlantic has four 8691-1 hp. Hispano-Suiza liquid-cooled engines mounted in tandem on the wing and top speed of 220 m.p.h. Few details. Aviation, September, 1937, page 54, 1 illus.

French Airplanes. Bréguet 462 Vultur bimotored bomber (two Gnôme Rhône 14N 950-hp. engines, maximum speed 402 km./hr.), Bréguet 470 Fulgur bimotored 12-passenger transport (two Gnôme Rhône 14KAF 850-hp. engines, maximum speed 385 km./hr.), and Salmson D6 Cri-Cri training and sport plane (Salmson 9 Ad R 60-hp. engine, maximum speed 139 km./hr.). Construction, characteristics, and performance. La Technique Aéronautique No. 144, 1937, pages 66–71, 6 illus.

GERMANY

The German Trans-Oceanic Seaplane Ha-139. Hamburger Ha-139 twin-float four-engined low-wing monoplane with a gross weight of 16 tons and range of 3107 miles at a cruising speed of 155 m.p.h. Brief notes. Aero Digest, September, 1937, page 115, 1 illus.

Arado Ar-77 bimotored trainer has a speed of 240 km./hr. and range of 720 km. at a cruising speed of 200 km./hr. Photograph only. Les Ailes, September 9, 1937, page 8, 1 illus.

Junkers Ju-90 four-motored 40-passenger commercial transport can be equipped with engines developing from 800 to 1000 hp. and will have a payload of 4 tons, a range of 1000 km., and a maximum speed of 380 km./hr. Brief reference. Les Ailes, September 9, 1937, page 7.

The Cult of the Inverted Vee. B.F.W.-109 airplanes, one with Daimler-Benz and one with Junkers inverted-vee liquid-cooled engines installed, and a Dornier Do.17 twin-engined bomber with two Daimler-Benz engines. Photographs only. Flight, August 19, 1937, page 195, 3 illus.

The Four Winds. A landplane version of the big four-engined Hamburger seaplane designed for transatlantic service is to be built. It will have four B.M.W. 132 engines. Brief reference. Flight, August 12, 1937, page 159.

New Military Aircraft. Heinkel He 112 single-seater pursuit (12-cylinder vee watercooled engine), Arado Ar 95 two-seater reconnaissance seaplane (same type of engine), and the Henschel two-engined combat airplane. Photographs with a few details of the first two. Luftwehr, September, 1937, pages 388–389, 3 illus.

North Wind and North Sea. Heaviest equipment yet to be catapult-launched will be used by Deutsche Lufthansa in its experimental work on North Atlantic routes. Take-off of the twin-float four-motored Nordmeer and Nordwind Ha-139 seaplanes from the water was accomplished in less than 30 seconds with a load corresponding to a flying range of 2180 miles. Few details and photographs of the seaplane and its parts. Aviation, September, 1937, pages 40–41, 7 illus.

Safety First. With fixed full-length slots and flaps, the Fieseler Stork has a fully-controlled stalled glide at an air speed of 24 m.p.h. and an undercarriage designed to take a vertical velocity of 15 ft./sec. Standard power unit is the 240-hp. Argus vee-eight, giving the machine a maximum speed of 130 m.p.h. Photograph only. Flight, August 19, 1937, page 199, 1 illus.

With Foreign Builders. Arado Ar 96 high-performance general-purpose military schooling plane is powered with a 300-hp. inverted-vee 8 Argus aircooled engine and has a maximum speed of 202 m.p.h. Few details. Aviation, September, 1937, page 55, 1 illus.

GREAT BRITAIN

The Battle's Performance. Fitted with a Rolls-Royce Merlin I glycol-cooled 1050-hp. engine, the Fairey Battle is capable of 210 m.p.h. at sea level, and 257 m.p.h. at 15,000 ft. Cruising range with normal load is 1000 miles. Performance figures only. Flight, July 22, 1937, page 103.

A Bomber's Bridge. Pilot's cockpit of a Handley-Page Harrow MkII heavy bomber. Photograph only showing location of the flying controls, including the long operating lever for the Dowty flap gear, and the Hobson mixture and throttle controls associated with the twin Pegasus XX fully-supercharged radials. Flight, August 26, 1937, page 208, 1 illus.

Britain's Smallest. T.K.4 slotted and flapped racing monoplane designed and built by students of the DeHavilland Technical School has a wing span of 19 ft. 8 in. and is designed for a speed of 215 m.p.h. Long description and illustrations of the specia lnose cowling and other parts. Flight, August 12, 1937, pages 164a–164c, 10 illus.

Drawing of joint and lock on its Dowty retracting gear. Aeroplane, September 15, 1937, page 346, 2 illus.

The Four Winds. It is understood that the British Air Ministry is specifying camouflage for new fighters. Those normally operating during the day will be painted blue on their lower surfaces, while night fighters will probably have the "night" finish applied to bombers. Brief reference. Flight, August 19, 1937, page 182.

Each of the Armstrong-Whitworth Ensign four-engined transports will cost £54,000. Brief reference. Flight, August 12, 1937, page 159.

For Light Reconnaissance. New Fairey Sea Foxes are powered by the Napier Rapier VI engine, the 370-hp. (at 4750 ft.) 16-cylinder "small sister" of the H-type Dagger. The Sea Fox is specially designed for arduous catapult work. Photograph only. Flight, July 15, 1937, page 66, 1 illus.

Good Hunting. Queen Bee radio-controlled target airplane was shot down when at an altitude of 4000 ft. and a mile from the anti-aircraft guns. Photographs show the Queen Bee as it is being catapulted into the air and some of the damage done to the plane. Flight, August 26, 1937, page 221, 3 illus.

The Fairey Battle. The Fairey Battle bomber (Rolls-Royce Merlin F engine developing 1035-hp. at 16,000 ft.) carries nearly two tons at 257 m.p.h. Long description of construction, including characteristics, performance, and cutaway drawings showing location of equipment, and structure. Aeroplane, August 18, 1937, pages 197–199, 16 illus. Flight, August 19, 1937, pages 188a–188d, 189, 19 illus.

The Field. The nineteen types of airplanes entered in the King's Cup Race. Few details and photographs of each. Flight, September 9, 1937, pages 260a–260d, 261, 18 illus.

A Proportional Departure. Miles Hobby is longer than its span and has a 9-ft. 6-in. undercarriage track. It is powered with a Gipsy Major Series II engine. Drawing and few details. Flight, September 9, 1937, pages 260, 266, 269, 4 illus. Photographs only. Aeroplane, September 8, 1937, pages 272, 275, 2 illus.

Official Vagaries. "The final lunacy is in the R.A.F. itself. All this money is spent on producing imperfect streamlines and more money is spent on giving them doubtfully useful polished surfaces, and then when they are about to be delivered to the R.A.F. all those machines which are to be used for night flying are sprayed with camouflage paint. . . The joke is that this shadow paint has to be rough—as rough as rough sandpaper pretty nearly." Criticism also of protruding bomb racks, windmills, and machine-gun casings allowed and of the large amount of money spent on research to discover the right streamline. Aeroplane, September 8, 1937, page 275.

Types in the King's Cup Race. The seven new types of airplanes entered in the Race include the C. W. Cygnet (130-hp. Gipsy Major), Miles Hobby, Miles Magister, Miles Whitney Straight, Moss monoplane (Pobjoy Niagara), the De Havilland Technical School's humpy little T.K.4, and the Wicko high-wing monoplane. The total number of diverse types entered is 19. Drawings, photographs, and few details of each. Aeroplane, September 8, 1937, pages 283–287, 39 illus.

The Upper Component. Float-plane Mercury (four Napier Rapier engines), which is to be the flying-off part of the Mayo Composite seaplane is shown in construction. Two photographs of the Maia, lower component, are shown on another page. Aeroplane, August 18, 1937, pages 183, 185, 3 illus.

Air and Water. The Mercury, upper component of the Short Mayo composite aircraft, has four 350-hp. Napier Rapier engines and a range of about 3500 miles in still air. With a payload of 1000 lb. the machine will have a cruising speed of about 160 m.p.h. Brief reference. Engineer, September 10, 1937, page 283.

The King's Envoy. Specially prepared Airspeed Envoy (two Armstrong Siddeley Cheetah Xs engines) maintained for the transport of Royalty. Top speed is over 200 m.p.h. Photograph only. Flight, August 5, 1937, page 144b, 1 illus.

Maia and Mercury Short Composite Aircraft. Differences between the Maia, lower component, and the Empire flying boat, and reference to its performance in flight tests. With four Napier Rapier engines and fuel for 3500 miles at about 160 m.p.h. the upper component Mercury will have a pay load of 1000 lb. and will carry nearly 10,000 lb. of fuel and oil. The Maia will weigh approximately 25,000 lb. when carrying fuel for the launch and reserve for emergencies. Economy of operation compared with the Caledonia and Cambria, as well as Atlantic experiments being undertaken by France and Germany are discussed in an Editorial. Flight, August 19, 1937, pages 178–181, 3 illus.

"The Mercury must be the cleanest four-motor float seaplane ever built. Even with floats the airspeed indicator shows that the Mercury is 20 m.p.h. up on its estimated cruising speed of 160 m.p.h." Design and flight performance of the upper component of the Short Mayo composite aircraft. Aeroplane, September 15, 1937, pages 307–308, 2 illus.

Results obtained in flight tests of the Mercury. Flight, September 16, 1937, pages 290–292, 6 illus.

The Victors. Gardner's winning Percival Mew-Gull (Gipsy Six II) and the Miles Whitney Straight which won first and second places in the King's Cup Race. Few details and equipment of the three planes. Drawings of interesting features of the airplanes competing in the race are given in preceding articles. Flight, September 16, 1937, page 286, 3 illus.

Equipment of some of the airplanes flying in the Race. Aeroplane, September 15, 1937, page 346, 2 illus.

ITALY

An Italian Flying Boat. C.A.N.T. Z-506, newest three-engined commercial seaplane designed by M. Zappata, carries twelve passengers and crew of four, has a range of 800 miles at a cruising speed of 200 m.p.h., and has established ten new world seaplane records. The seaplane has been fitted with both liquid and aircooled engines and in its commercial form has been fitted with three Isotta Fraschini Asso XI R 12-cylinder liquid-cooled engines developing 840-hp. at 2250 r.p.m. Description of design and records obtained. Aircraft Engg., September, 1937, page 239, 2 illus., 1 table.

Another Record Breaker. Cant Z-508 flying boat (three 900-hp. Isotta-Fraschini Asro XI RC water-cooled 12-cylinder vee engines) set a new class record by carrying a load of 5 tons over 1242 miles at an average speed of 154 m.p.h. It is supposed to have a range of 8000 miles. Photograph only, Aeroplane, September 15, 1937, page 317, 1 illus.

JAPAN

With Foreign Builders. MIP-94 reconnaissance airplane (500-hp. engine, cruising speed 186 m.p.h.) for Japanese Army, and the new monoplane (800-hp. Kawasaki engine, 92-ft. wing span) reported to lift a fuel load of 12,000 lb. and to have a range of 10,000 miles. Very few details of each and photograph of the latter. Aviation, September, 1937, page 54, 1 illus.

Japan announces plans for a Tokio-New York nonstop flight in an airplane declared to have a range of 10,000 miles. Brief reference. Western Flying, September, 1937, page 46.

SOUTH AFRICA

Building Fighting Planes. Hawker Hartbees two-gun general-purpose airplane being built from raw materials in the South African Air Force shops may be used as a two-seater fighter and, being equipped with electrical bomb-release gear, also as a day bomber. The airplane is powered by a 600-hp. Rolls-Royce Kestrel engine and has a top speed of 186 m.p.h. at 11,000 ft. Brief reference. Engineer, September 10, 1937, page 282.

U. S. A.

Bellanca Model 28-90. Combining a useful load-carrying capacity of 2425 lb. with a maximum speed of 280 m.p.h., the Bellanca Model 28–90 is a two-place low-wing braced monoplane with completely retractable landing gear. It is powered by a P & W Twin Wasp SBG engine developing 900 hp. at an altitude of 6500 ft. Long description. Aero Digest., September 1937, pages 58, 62, 5 illus.

Lockheed 14 Transport. New twin-engined Lockheed 14 is also available as a convertible transport bomber, or as a bomber carrying a crew of four, and a variable bomb load, and having medium long-range fuel capacity. Armament consists of four 0.30-caliber flexibly mounted guns and a nose turret houses two guns as a twin installation. The commercial transport with 1050 b.hp. has a maximum speed of 247 m.p.h. at 6700 ft., cruising

speed of 220 m.p.h. at 12,000 ft., useful load of 7350 lb., and range of 1660 miles. It is normally fitted with two P & W Hornet SIEG or Wright Cyclone G-3 engines. Long description, specifications and estimated performance of the commercial version powered with P & W Hornet engines, and details of the armament of the bomber. Aero Digest, September, 1937, pages 45–46, 3 illus., 1 table.

Pan American Airways "Atlantic Clipper." Atlantic Clipper three-deck flying boats being built by Boeing for Pan American Airways, are designed to carry 50 passengers on 24-hour schedules between America and Europe, and to accommodate 75 passengers on shorter runs. They will weigh 42.5 tons fully loaded and are powered by four 1500-hp. Wright Cyclone engines giving a maximum speed of 200 m.p.h. and cruising range, with 50 passengers, of more than 3200 miles. Cut-away diagram showing interior details, Aero Digest, September, 1937, page 54, 1 illus,

Ryan Cabin Monoplane. New Ryan S-C all-metal three-place cabin airplane has a top speed of 152 m.p.h. at 3000 ft. and is powered with a Menasco C4S 150-hp. engine. Long description, characteristics and performance. Aero Digest, September, 1937, pages 53–54, 4 illus., 1 table.

Advanced Trainer. Two-place low-wing monoplane designed and built by students at the Boeing School has a gross weight of 3200 lb. and an estimated cruising speed of 223 m.p.h. at 10,000 ft. It is powered by a Wright Whirlwind 320-hp. engine. Description, characteristics, and estimated performance. Aviation, September, 1937, page 50, 2 illus., 1 table.

Few details. Western Flying, September, 1937, page 44, 1 illus.

Aeronca Seaplane. Aeronca Model K equipped with Edo floats. Few details. Aviation, September, 1937, page 46, 1 illus.

New Military Aircraft. Bell XFM-1 and Northrop A-17 airplanes. Photographs and few details. The Bell airplane is said to have an estimated maximum speed of about 480 km./hr. Luftwehr, September, 1937, pages 389–390, 2 illus.

Brief description, Bell XFM-1. Aviation, September, 1937, page 49, 2 illus.

Photograph. Caption states the airplane is armed with a pair of cannons. Flight, August 12, 1937, page 163, 1 illus.

The Four Winds. Seversky claims to have completed tests with the world's fastest two-seater fighter which has been built for export. The machine has aroused great enthusiasm in China and Russia and substantial contracts are likely to ensue. Tankage is sufficient for a range of 4000 miles in overload condition. Brief ref. Flight, August 12, 1937, page 159.

Grumman's New Amphibian. Model G-21 5–7 place high-wing commercial amphibian powered by two 450-hp, P & W Wasp Jr. SB engines. Maximum speed is 205 m.p.h. at 5000 ft. Short description, characteristics, and performance. Western Flying, September, 1937, page 44, 1 illus.

The Herrick Vertaplane. R. H. McClarren. Upper rotor wing of the biplane combination is symmetrical along the center line of the span and is devised so that it can be released from the fixed position and started to rotate and will continue to rotate and operate as any rotating wing. Seven conversions from airplane to gyro have been made in the air, one at 1500 ft Maximum speed is in excess of 100 m.p.h. and landing speed below 30 m.p.h. Short description and general specifications. Aviation, September, 1937, pages 53, 76, 2 illus., 1 table.

Hugo Boat Bomber Tested. Sikorsky XPBS-1 experimental flying boat bomber built for the U. S. Navy is powered by four P & W Twin Wasp 1050-hp. engines, It is said to have a speed in excess of 200 m.p.h. and to be 6 tons heavier than Pan American's Sikorsky Clipper. References to armament, 110-volt electrical system supplied by a generator driven by an auxiliary gasoline engine, radio, and other equipment. Western Flying, September, 1937, pages 38, 42, 1 illus.

Few details. U. S. Air Services, September, 1927, page 20, 1 illus.

Photograph only. Aviation, September, 1937, page 67, 1 illus; Les Ailes, September 23, 1937, page 8, 1 illus.

It Weighs 85,000 Pounds. Giant 75-passenger flying boat Boeing is building for Pan American Airways. Cutaway diagram and photographs of parts of the boat in construction. Western Flying, September, 1937, page 22, 4 illus.

Cutaway drawing. U.S. Air Services, September, 1937, page 14, 1 illus. Aviation, September 30, 1937, page 64, 1 illus.

Ryan Re-enters the Cabin Field with Model S-C. Long description of airplane, its flight characteristics, equipment, and specifications. Aviation, September, 1937, pages 42–43, 46, 6 illus.

New wing, tail, and air brake described with characteristics and performance. Western Flying, September, 1937, page 28, 2 illus.

Sub-Stratosphere Experiment. "The heart and brain of the U. S. Army Air Corps' new Lockheed." Photographs showing the cockpit and emergency oxygen supply, the special door in the rear bulkhead, and controls and dials on the technician's panel. Flight, August 26, 1937, page 213, 3 illus.

To Suffer Fools Gladly. Gwinn Aircar two-seat cabin biplane of 24-ft. wing span has a tricycle undercarriage and cannot be stalled or spun by the pilot. Long description of small American sport plane with comments on the design from the British point of view. The latest Hammond and a new Bellanca for a captain in the Rumanian air force are also illustrated. Aeroplane, September 15, 1937, pages 337–338, 4 illus.

Sikorsky Patrol and Bombing Flying Boat. XPBS-1 four-engined all-metal high-wing full-cantilever flying boat built for the Navy and powered by four P & W Twin Wasp 1050-hp. engines. Armament consists of bow, rear, and center gun turrets. The flying boat has a military load-carrying capacity comparable with that of any known existing airplane. Description but no mention of performance. Aero Digest, September, 1937, page 68.

U. S. S. R.

A Flight of Fancy. "Figures from an analysis of the known characteristics for the alleged record-breaking machine, the A.N.T.-25," are offered as evidence that the long-distance record claimed by the Russians who flew from Moscow to Los Angeles was a fake. Aeroplane, September 8, 1937, page 273.

The Aviation Show at Moscow. A tailless bimotored bomber designed by Kalinine, a four-motored seaplane of 24–25 tons (four M-34 engines), and two four-motored T.B.-6 bombers are mentioned as among the military airplanes taking part in the exhibit. The T.B.-6 should be called a five-motored airplane as it has a Hispano-Suiza 12-Y engine located in the interior of the fuselage to drive the two-stage supercharger for the four M-34 engines located in the leading edge of the wing. This airplane has a speed of nearly 500 km./hr., at between 8000 and 9000 meters, and carries a load of 3 tons of bombs over 2000 km. Account of the Show and references to these and other military airplanes taking part in the maneuvers. Les Ailes, September 9, 1937, pages 5–6, 1 illus. Aeroplane, September 22, 1937, page 351. (Translation from Les Ailes.)

With Foreign Builders. LIG-5 and LIG-8 all-wood sport planes, a two-seat wood amphibian and a "Flying Laboratory" glider designed for experiments and meteorological observations during gliding meets. Brief references only. Aviation, September, 1937, pages 55, 80.

Manually-Operated Aircraft

Man-Power Flight. G. Bradshaw. Practical experiments with a glider and automobile, both manually propelled, and work yet to be accomplished in this field. The author feels he has definitely proved that "lift by reaction" is sound and efficient. Editorial criticism is included. Flight, July 15, 1937, pages 76c, 76d, 77–78, and 68, 4 illus.

Author's reply to editorial criticism, and letters from others. Flight, July 29, 1937, pages 117–118.

Further discussion by the author dealing with the ideal glider, flap valves, and weight reduction. Flight, August 12, 1937, page 162.

The Manually-Propelled Cycleplane According to an Italian Engineer. B. Posniak. Three-place tailless airplane propelled by muscular force is described. The author considers that a power output of 6 hp. can be produced by two people operating the propeller. Les Ailes, September 9, 1937, page 13, 3 illus.

Air Transportation

Atlantic Routine. Experimental flights of the Imperial Airways' Caledonia and the Pan American Sikorsky S.42B flying boats across the Atlantic. Account of flights, a few details of the Caledonia, description of the Sikorsky, and comments on the navigational methods employed by her crew. Flight, July 15, 1937, pages 68–72, 8 illus, 2 tables.

Russia Says So. "Russian reports say that the U. S. Government has authorized the Russian Aeroflot to set up agencies in Seattle and San Francisco for a regular air service between Russia and the U. S. A. by way of the Arctic." Brief reference. Aeroplane, September 15, 1937, page 310.

Aircraft Maintenance

Effect of Design and Construction on Maintenance and Overhaul of Naval Aircraft. F. G. Arnold. Matters in which the designer of naval aircraft can be of assistance to the overhaul base. Discussion includes: sources of corrosion and how they may be avoided; design of steel forgings so that, in emergency repair, they may be replaced by welded steel fittings; fitting installations made so that they may be removed as units; heat treating of highly stressed steel components; the carry-through design of a structure as a deciding factor in the amount of damage caused by a minor crash; provision of stress data on airplanes to be serviced to facilitate design repairs or reinforcements; designing wing tips for easy replacement; overhaul of stressed-skin wings; criticism of the push-pull tube control guided by rollers; use of bushings for pin and bolt holes in controls and structures; standardization of airplane parts; use of standard machine screws and fittings; and provision of complete and accurate airplane drawings. S.A.E. Preprint for Meeting, October 7–9, 1937, 7 pages.

Maintenance Problems of Army Airplanes. Major J. T. Morris. Air Corps system of maintenance, and the problems and difficulties involved in depot maintenance of Army airplanes and engines. Standardization of parts and adherence by manufacturers to the requirements of the Engineering Section of the Material Division are urged. Operations through which aircraft undergoing overhaul must pass are reviewed and important developments in airplane overhaul are mentioned. Dismantling and inspection of engines are also discussed and some improvements are referred to. S.A.E. Preprint for Meeting, October 7–9, 1937, 9 pages, 1 illus.

Aircraft Accidents

Causes of American Air-Line Accidents. By an Air Traveller. Information picked up about air accidents to transport airplanes in the United States during the past winter with the comments that many could have been avoided and that familiarity has tended to breed contempt. Aeroplane, September 8, 1937, pages 295–296.

An Accident in the Netherlands. Accident to the new F.K. 52 two-seater fighter. As the airplane sharply pulled out of a dive, the transparent cover over the pilot's cockpit flew off cutting the top off the fin and rudder, Brief account. Aeroplane, August 18, 1937, page 186.

High-Altitude Flight

Problems of the Altitude Record Flight. A. Swan. Difficulties of high-altitude flight and how they were overcome in the flight of Flight Lt. M. J. Adam to 53,937 ft. in a Bristol 138A airplane. The Bristol Pegasus engine and its special superchargers, carburetor and ignition system, the airplane developed for high-altitude research, the propeller used, and the special pilot's pressure suit and helmet are described in detail. Method used by the F.A.I. in computing the height is explained and the instruments described, A résumé of the pilot's report of the flight is included. Long article. British Association paper. Engineering, September 10, 1937, pages 280–284, 12 illus., 4 tables.

Propellers

Airscrew Blade Vibration. Major B. C. Carter. As an extension of crankshaft torsional-vibration investigations, these extensions in the mathematical treatment were developed at the Royal Aircraft Establishment to clarify ideas concerning modes of vibration that may occur and also to form a new basis for experimental investigation. Results of vibration tests on a stationary magnesium propeller are given and compared with theoretical results. New experimental technique is described whereby photographic records may be obtained of blade-tip vibration relative to the hub in flight. Variants of a new device for exciting linear and torsional vibrations are described which are characterized by the magnitude of excitation at any frequency being capable of adjustment during running. A mathematical examination of flexural vibration of elastically encastred blades is included. Jour. Royal Aeronautical Soc., September, 1937, pages 749–785 and (disc.) 785–190, 22 illus, 4 tables, 27 equations.

Curves Developed for a Series of Driving Propellers. A. Toussaint. Results contributed by the vortex theory of propellers, the optimum series of propellers, and a practical method of calculating the propeller adapted to a given airplane and engine. La Technique Aéronautique No. 144, 1937, pages 100–117, 7 illus., 1 table, 31 equations.

Principles of the Single Blade Propeller. W. W. Everel. Everel single-blade automatic variable-pitch propeller is a statically- and dynamically-balanced unit, the blade being balanced by a suitable counterweight. Long description. Aero Digest, September, 1937, page 71, 5 illus.

Records and Races

On the Dullest King's Cup Race. C. G. Grey. Criticism of the handling of the King's Cup Race and the lack of new types of aircraft which will be entered. A second article, entitled "How the Race for the King's Cup Will Be Flown," describes the program and gives the entries. A third gives the course for the Race, and a fourth the pilots entered. Aeroplane, September 8, 1937, pages 276–278, 282, 288–291, 292–294, 38 illus.

The Way Round. H. A. Taylor. Impressions received during an exploratory trip over most of the King's Cup route and map of the course. A second article contains personal notes on the pilots participating, and a third the rules and regulations and list of entries. Flight. September 9, 1937, pages 248–256, 257–260, 262–263, 44 illus, 4 tables.

On the King's Cup Race. C. G. Grey. General account of the Race which was won by Charles Gardner in a Mew Gull. A second article gives comments on the airplanes participating and drawings of interesting features and a third discusses the performance of the airplanes in the Race. A fourth entitled "Bumping Round Britain," by F. D. Bradbrooke describes a flight in a competing Short Scion. Brief articles commenting on the race follow. Aeroplane, September 15, 1937, pages 319–336, 41 illus.

Account of race and drawings of interesting features of the competing planes. Flight, September 16, 1937, pages 276–285, 26 illus., 4 tables.

The Four Winds. Marek and Emmer, two Austrians, have established a new altitude record for hot-air balloons by reaching 24,700 ft. Brief reference. Flight, July 29, 1937, page 119.

A balloon of 120,000 mc. has been constructed in Poland for stratospheric ascents in which it is hoped to attain a height of 30,000 meters. Brief ref. Les Ailes, September 9, 1937, page 6.

Russia's Fine Effort. Chart comparing the Russian flight of the A.N.T. 25-1 monoplane with long distance records of other years, and details of the flight. Flight, July 22, 1937, page 110, 1 illus.

GLIDING

Soaring in Derbyshire. British national soaring competitions at Great Hucklow. Account of meeting. Flight, September 16, 1937, pages 299–300, 1 illus,

Soaring Internationally. Account of the International Soaring Competition at the Wasserkuppe. Flight, July 15 and 22, 1937, pages 81–82 and 98–99, 5 illus.

Aircraft Instruments

Computer Simplifies Navigation Problems. With the American Airlines navigational computer the pilot can determine true air speed of the plane, compass course he must follow, fuel consumption and flying time between between landings. It can be used also to calculate wind direction and velocity and it allows the pilot to keep an accurate check on upper air information provided by company meteorologists. Details of computer and its operation. Aero Digest, September, 1937, page 88, 3 illus.

Low-Cost Sextant. Boyce-Meier sextant for use in studying navigation. Few details. Aero Digest, September, 1937, page 90.

The Windicator. Device applying the law of the parallelogram of forces to determining compass bearing correction to allow for winds of known velocity and direction. Description. Aero Digest, September, 1937, page 76, 2 illus, 1 table.

Finding Your Way in the Air. Lt. Commander P. V. H. Weems. Modern technique and equipment for dead reckoning. Continued. Aviation, September, 1937, pages 38–39, 76, 6 illus.

Flight Analyzers Adopted. Automatic and constant records of the operation of each scheduled flight are provided by the flight analyzers adopted by United Air Lines. Few details. U.S. Air Services, September, 1937, page 30.

Instrument Planning. Wing Commander G. W. Williamson. Blind-flying instrument panel just adopted by the Royal Air Force and its instruments are described. Free gyro characteristics, the artificial horizon, and a new type of sensitive altimeter in which the pointers read like those of a clock are discussed in detail. A special mounting for the new panel is illustrated in a drawing and photographs of the new panel, as well as a typical American array of a few years ago, used on the Boeing 247s are included. Flight, August 19, 1937, pages 193–195, 3 illus.

Miniature Ball Bearings. Small ball bearings have been developed in Switzerland to take place of plain or jewel bearings in such devices as small electric motors, recorder, meters, clockwork, speed indicators, tachometers, and pressure gages. Overall dimensions range from 1.5 mm. upward but complete bearings of only 1 mm. overall size will shortly be available. Brief description and reference to results of tests to find the reduction in friction resulting from their use. Automobile Engr., August, 1937, page 282, 1 illus.

New Recording Apparatus for Aeronautical Research. H. Freiso. Recording apparatus developed for accurately measuring small distances is applied to extensometers, accelerometers, pressure speed indicators, pressure heads, parachute opening shock absorber, and cable force recorder. For greater distances, a recording tachometer, and deflection and vibration recorders have been developed. The measuring distances are recorded according to size either on a glass or steel cylinder, or on a film strip and are evaluated under a microscope or micro-photographically. Long description of the recording device and driving mechanism and applications. DVL report. Luftfahrtforschung, August 20, 1937, pages 373–386, 48 illus.

Airport Equipment

Assisting the Take-Off. "Experimental catapults have been made and used, notably by the Royal Aircraft Establishment for launching heavy bombers." Advantages of high wing loading, the Mayo composite aircraft, and practical problems to be solved in its operation are discussed in the first issue.

The second issue describes the successful demonstration at Hendon of refueliug in the air, given by a Boulton and Paul Overstrand refueled from a Vickers B.19/27., and takes up the development of the catapult giving data on different types developed by the R.A.F., especially the field type or "accelerator." Future requirements are predicted. Flight, July 22 and 29, 1937, pages 100a–100d and 124a–124d, 10 illus.

Automatic Wind Tee. New Wilhelm device indicates landing direction automatically, wind or no wind, and operates on a gravity cam principle. Few details. Aviation, September, 1937, page 59.

Defense of Airports Against Air Attack. E. Raab. Precautions to be taken to make it difficult to locate airports from the air and to limit the effectiveness of air attack. From Ny Militaer Tidskrift, Feb., Luftwehr, September, 1937, pages 379–380, 1 illus.

Air Conditioners for Airliners. Air Conditioner specially built by General Refrigeration Corporation for supplying air to American Airlines' transport planes. Details of equipment by means of which a 70° temperature is established in a 21-passenger airplane in about 10 minutes. Aero Digest, September, 1937, page 88.

Coffing Jacks for Aircraft. Wing jack and tail jack used by American Airlines. Aero Digest, September, 1937, page 90, 1 illus.

Towing Vehicles for Airliners. Special Mercury 6-wheel towing unit developed for handling large transport airplanes has a maximum drawbar pull of 4000 lb. and is capable of handling equipment as large as the projected Douglas DC-4. Aero Digest, September, 1937, page 90, 1 illus.

Electrical Equipment

Caustic Capacity. Advantages of alkaline batteries which are now being supplied to the R.A.F. by Batteries Ltd., and used as standard equipment on Short Empire flying boats. Brief note. Flight, September 9, 1937, page 261.

Fire Extinguishers

Tackling Fire at the Source. Qualities required by the British Air Ministry in fire-extinguishing installations for aircraft use, and equipment produced by Graviner Manufacturing Company to comply with these requirements. Methyl bromide is used and the extinguisher proper is a three-pint copper bottle having a discharge head with electric fuses. Description and installation plan for a multi-engined airplane. Flight, July 15, 1937, page 76b, 2 illus.

Ice Elimination Equipment

Short Spans. Improved rubber "overshoe" deicers approved by the B.A.C. have fabric reinforcing strips installed in the rubber covering so that any tear developing in the covering will stop at the rib. Brief reference. Western Flying, September, 1937, page 38.

Miscellaneous Equipment

Fashion Note for the Service. Irvinsuit ordered in quantity for the R.A.F. is made of thick soft leather lined with inverted lambskin. Helmet, jacket, mittens, and trousers all make special coldproof seals with one another. Photograph only. Flight, September 16, 1937, page 300, 1 illus. Aeroplane, September 22, 1937, pages 373–374, 5 illus. (Longer description.)

Fire-Proof Suits. New suit brought out by Bell's Asbestos and Engineering Supplies, Ltd. is cut on the lines of the standard R.A.F. overalls but is made of hard-wearing closely-woven light asbestos cloth. Very brief note. Aeroplane, September 15, 1937, page 346. Flight, September 16, 1937, page 292.

PX's. To demonstate the possibilities of air rescue, a pilot flying at 2000 ft. picked up a person on the ground. About 2300 ft. of cable was used. Brief ref. Western Flying, September, 1937, page 46.

Approved at Last. Henderson crashproof fuel tank approved by the British Air Ministry has been shown to be leakproof and fireproof even when penetrated by incendiary bullets. When dropped under conditions simulating a crash at 50 m.p.h., the tank was 100 percent efficient. The tanks are made of metal, have no rivets and are not welded. Secret of the tank lies in its self-sealing walls. Few details. Aeroplane, August 18, 1937, page 211.

Ball Bearing-Equipped Control Surfaces. D. L. Holbrook. Advantages of the use of ball bearings in flight control systems, and other applications of ball bearings in aircraft and engines. Mention is made of the approximately 700 antifriction bearings used in the four-engined Boeing bomber, the preponderance being of the ball-bearing type. Aero Digest, September, 1937, pages 48, 50. 6 illus.

Parachutes

A Parachute Lesson. Photographs of an accident to a parachute with brief comment. Aeroplane, September 8, 1937, page 296, 5 illus.

Com-Pak Chute. Switlik parachute designed for the Taylor Cub and other small airplanes measures only 11½ in. across but contains a standard 24-ft. canopy. Few details. Aviation, September, 1937, page 58.

Photography

Air Survey. A project exists to make a complete triangulation of Great Britain by aerial photographic survey. Brief note. Aeroplane, September 15, 1937, page 311,

Cameras Civil and Militant. Williamson camera guns used in recent air exercises. Few details and reference to return of the British Graham Land Expedition from the Arctic where nearly 1000 miles of coastline were mapped from the air. Aeroplane, August 18, 1937, page 211.

Metals

Quality Control of Aluminum Alloy Aircraft Castings. K. R. Van Horn and H. J. Heath. Common structural variations in aluminum-alloy castings which affect their strength and serviceability, indirect and direct methods of quality control, and the proof-load test and its limitations are considered. Radiographic examination is taken up in detail including the technique for maximum sensitivity and definition, and the interpretation of radiographs. Static breakdown tests are described. The relationship between control and developmental tests and service performance is discussed and an example given of the effect of discontinuities in a casting on tensile, fatigue, and impact characteristics. S.A.E. Preprint for Meeting, October 7–9, 1937, 15 pages. 2 illus.

Technology and Metallurgy of Bearing Metals. F. Bollenrath, W. Bungardt, and E. Schmidt. Lead bronzes of importance in airplane-engine construction were investigated by means of several established melting tests, and the influence of melting practice and chemical composition on the quality of the lead distribution was determined. First part of the article considers investigations of various other bearing metals and draws conclusions as to their behavior in practice. DVL report. Luftfahrtforschung, August 20, 1937, pages 417–425. 18 illus., 4 tables.

Stainless Steels. H. E. Blank. Jr. Stainless steels produced in the United States, production methods, and a table of typical applications to automotive vehicles and aircraft. Automotive Industries, September 18, 1937, pages 382–390, 400, 401. 19 illus.

Alloys and the Atlantic. Advantages of Alclad aluminum alloys and properties of the two Alclad alloys used in the Short Empire boats. Short note. Flight, August 5, 1937, pages 144b. 1 table.

Engine Design and Research

The Angle of V Engines. K. Schlafke. The harmonic having a frequency equal to six times the crankshaft r.p.m. disappears entirely for an angle of 90°. Torsional-vibration characteristics of the 12-cylinder V engine are also discussed. From VDI. Automotive Industries, August 28, 1937, page 272.

Engine Test with Closed Air Jacket. Six-cylinder aircooled engine with completely closed air jacket was tested at Stuttgart Technical College. Individual cylinders with cooling fins and a finned head were used and the air blown over these parts from side to side. Cylinders and heads were enclosed in a housing which confined the cooling air. To the cylinder-cooling passages the air was admitted through quadrilateral openings wider near the top so the upper part would receive the most air. Brief abstract from Kraftfahrtechnische Forschungsrabeiten No. 4. Automotive Industries, August 28, 1937, page 272.

Horsepower at Altitude. G. O. Anderson and M. Thomas. Concise but accurate method of determining the corrected power and boost, without the use of the several long and laborious stages outlined in AP.840 Addendum A. Authors are on the staff of the Engine Department, Bristol Aeroplane Company. C. Brooke's method, described in a previous issue, is also criticized. The formula for horsepower correction is divided into two parts, one pertaining solely to the boost pressure correction, and the other to the correction for temperature and exhaust back pressure. Only two charts are necessary from the first of which boost correction can be obtained directly, while the horsepower correction factor is merely the product of the factors obtained from both charts. Aircraft Engineering, September, 1937, pages 233–238, 8 illus., 6 tables, 8 equations.

Metallurgy and the Aero Engine. D. R. Pye. Thermal and mechanical problems introduced by increase in power in aircraft engines during the last five years and developments in metallurgy to solve them. The discussion covers: piston problems; engine temperatures; causes of valve failure; effect of fuel composition; cooling problem; prevention of engine seizure; metal surfaces; invisible lubrication; nature of friction; abrasion of the metal surfaces; effect of high surface temperatures; the Beilby layer; variation in thickness of the amorphous layer; stability of the amorphous layer; Finch's observation that polished surfaces may or may not remain amorphous, and his suggestion that if a suitably oxidized magnesium-aluminun alloy is used, it is possible by polishing it to form spinel with a permanently amorphous Beilby layer; cast iron as a bearing material; and the necessity for cooperation between metallurgist and physicist. British Institute of Metals paper. Metal Industry, September 10, 1937, pages 249–254. Engineer, September 10, 1937, pages 292–294. 3 illus.
Abstract. Engineering, September 10, 1937, pages 291–292.

The Torsional Rigidity of Crankshafts. W. A. Tuplin. Formulas are devised on the basis of measured rigidities of a range of crankshafts and apply to equivalent length, nonuniform shaft, torsional strain of crankshafts, equivalent lengths of journal, pin and web in torsion, and webs in bending. Formulas of Geiger, Timoshenko, Carter, and Ker Wilson for equivalent length of crankshafts are quoted and criticized. Examples for checking the formulas are given with dimensional details of 17 crankshafts and a general procedure in development of a formula is outlined. Engineering, September 10, 1937, pages 275–277, 3 illus., 1 table, 8 equations.

Trend of Air-Cooled Aero Engines—The Next Five Years. A. H. R. Fedden. Most important types of aircraft and the four types of engines required to meet military and larger civil transport requirements; fuels; comparison of 1500-b.hp. aircooled radial using 100-octane fuel and the compression-ignition engine; engine layouts from the geometric aspect; illustrations of a 20-cylinder multi-bank 1000-hp. radial designed by the Bristol Company, Potez-Lorraine 12-cylinder flat engine, and Walter Sagitta 12-cylinder inverted vee; engine comparison on the basis of b.hp./sq.in. piston area; engine layouts from the aerodynamic aspect; effect of power plant weight and diameter and the comparative performances of twin-engined fighters; standardization of complete power units; a series of geometrical arrangements possible on a radial installation with wing chords of 12 and 16 ft.; two alternative cooling systems arranged for completely standardized power units; and services and accessories which the complete unit should include. Jour. Royal Aeronautical Soc., August, 1937, pages 635–663 and (disc.) 663–678, 17 illus., 10 tables.

The Development of the Automobile Radiator. J. Coltman. Cooling of *aircraft engines*, Essential requirements; recovery of work done in air cooling at 300 m.p.h.; liquids and cooling elements employed in liquid-cooled engines; use of cupro-nickel radiators for Belgian Air Force airplanes; glycol-cooled aircraft engines; latest type of radiators used on British Air Force aircraft; German radiator construction; trend of design in aircraft-engine radiators from 1911 to 1936; oil cooling problems, and details of a standard type of oil cooler supplied to the British Air Ministry. Radiators for marine engines and railway vehicles are discussed at the end of the article. To be continued. Engineer, August 27, 1937, pages 238–240, 7 illus.

Engine Maintenance from the Operator's Viewpoint. W. A. Hamilton. Progress in the design and operation of aircraft power plants in the past four or five years, and its importance to engine operation on present transport aircraft. Maintenance is referred to only in regard to increase in periods between overhauls. S.A.E. Preprint for Meeting October 7–9, 1937, 5 pages, 2 illus.
Scheme by which the entire engine and its exhaust manifolds are enclosed in the airplane wing. Invention of officers at the Royal Aircraft Establishment whereby the exhaust is used to convert drag into thrust. Very few details. U.S. Air Services, September, 1937, page 33.

Engine Installation

The Development of Successful Engine Installations. R. E. Johnson. Factors of the installation which may adversely affect engine operation or materially reduce the available engine operating efficiently as a unit of power development. Necessary design features of the cowling, oil coolers and oil, air-induction, exhaust, and fuel systems are discussed in detail. Requirements of engine controls and engine installation flight tests are mentioned. S.A.E. Preprint for Meeting October 7–9, 1937, 10 pages. 2 illus.

Engine Materials

Chromium Plated Cylinder Bores. Wear of the chromium-plated cylinder bore was only a third of that of the nitrided bore in a 1500-hour test run with a chromium-plated cylinder and cast-iron cylinder mounted on the same crankcase. Listard process of chromium plating is said to be applicable to automobile and aircraft engine cylinders. Very brief abstract, La Technique Moderne. Automotive Industries, September 25, 1937, page 422.

Engine Testing

Tomizuka's Electric Pressure Indicator. Improvements to instrument which automatically indicates and records compression changes in cylinders of high-speed internal-combustion engines. Diagram and few details of latest patent application of Kiyoshi Tomizuka, Aeronautical Research Institute, Tokio Imperial University. Applications suggested include studies of pressure variations in inlet and exhaust lines, and in fuel lines of injection engines as well as investigations of effect of superchargers, development of combustion phases in Diesel and gasoline engines, and of air pressure in tires under peak-load conditions. Brief abstract from Kogyo Zasshi, Automotive Industries, September 18, 1937, page 380, 1 illus.

Engines

The Aspin Engine in Detail. Rotary combustion chamber of the Aspin flat-four aircraft engine is in the form of a cup or cell set eccentrically in a cone the base of which is the top of the cylinder. The cone is rotated by gearing and a port in its side sweeps over the inlet and exhaust ports in the cylinder head, putting them in communication with the combustion chamber. Due to extreme turbulence within the cell during combustion, and completeness of combustion before the expansion stroke begins, the knock-producing condition associated with flame front does not exist. Long well-illustrated description and data for the unit developing 80 b.hp. at 4800–5000 r.p.m. and weighing 130 pounds. Flight, July 29, 1937, pages 130–131, 4 illus.

The Four Winds. The new medium-supercharged Bristol Mercury IX (890 max. hp. at 6000 ft.) satisfactorily completed a 200-hours' flight endurance test in a Hart with a Bristol constant-speed propeller. Climbs were made to 28,000 ft. and take-off usually occupied less than 5 seconds. Brief reference. Flight, August 12, 1937, page 159.
It is believed that the Junkers Jumo 210 640-hp. and the Daimler-Benz 900-hp. inverted vee engines which were fitted in some of the latest German military aircraft taking part in the Zurich meeting have been designed for direct gasoline injection. Brief reference. Flight, August 19, 1937, page 182.
Official international ratings for the Siddeley Tiger VIII two-speed supercharged radial engine give the maximum power with full supercharge at 14,250 ft. as 780 hp. at 2450 r.p.m. and take-off output (moderately supercharged) as 880–920 hp. at 2375 r.p.m. Brief reference. Flight, August 26, 1937, page 209.

One Thousand Hours! As a result of operating experience with over 2000 Gipsy Major engines, the DeHavilland Aircraft Company has decided to increase the recommended period between major overhauls from 750 to 1000 hours. Brief note on history of the engine. Flight, August 26, 1937, page 207.

Saurer Oil Engine. Ultra high-speed Diesel engine for cars has an annular slot-type injector Long description of engine and drawings of the Acro combustion head, Saurer cross-flow head, and the Saurer dual turbulence combustion head, and the injection timing governor, as well as photographs of the spray form of the annular slot nozzle, and of a device for testing fuel spray. Performance and fuel consumption curves included. Automobile Engineer, August, 1937, pages 283–289. 21 illus.

Two-Speed Blowers. D. L. Prior. Two-speed supercharger unit built by Armstrong Siddeley in 1930, and the unit now in use in the Armstrong-Siddeley Tiger VIII engine, standard power plant of the Whitley heavy bomber. Advantages of a two-speed blower are pointed out and curves are given to show the relationship between rotor tip speeds and power absorbed, temperature rise, and altitude, respectively. Flight, Aircraft Engr. Sup., July 29, 1937, pages 1–3, 5 illus., 1 table.

Two-Speed Supercharger. Gear-driven centrifugal type of supercharger developed by the Bristol Aeroplane Company. Very few details. Western Flying, September, 1937, page 44.

The Alvis Air-Cooled Engines. Pelides and Alcides two-row aircooled radial engines are Gnôme-Rhône prototypes and both are produced in moderately-supercharged as well as fully-supercharged form. Centrifugal superchargers with automatic boost control are employed. The Pelides 14-cylinder engine develops 1000/1050 b.hp. at 5000 ft. and the fully supercharged version 1000 b.hp. at 13,000 ft. Maximum power is 1375 b.hp. The Alcides 18-cylinder engine develops 1650 b.hp. at 5000 ft., and the fully supercharged version 1530 b.hp. at 1400 ft. Maximum power is 1750 b.hp. Characteristics only. Aircraft Engineering, September, 1937, page 244, 2 illus.

The Four Winds. "Preliminary data on the new semi-secret two-row Wright Cyclone" (GR-2600A-2 engine) gives the take-off output as 1500 hp. at 2300 r.p.m. on 95-octane fuel. Bore, stroke, displacement, compression ratio, and weight given. Brief reference. Flight, September 9, 1937, page 269.

French Engines. Characteristics and performance curves of the following Salmson engines: 6 AF 00 199-hp. 6-cylinder inverted inline; 6 AG 01 6-cylinder 310-hp. inverted inline; 7 ACa 7-cylinder 120-hp. radial; 9 AB 9-cylinder 260-hp. radial; 9 ABa 9-cylinder 325-hp. radial; 9 ADb 9-cylinder 59-hp. radial; 9 ADR 9-cylinder 70-hp. radial; 9 AG 01 9-cylinder 416-hp. radial; 9 Nas 9-cylinder 500-hp. radial; 9 NC 9-cylinder 156-hp. radial; 9 NCs 9-cylinder 165-hp. radial; 9 ND 9-cylinder 203-hp. 18 AB 18-cylinder 555-hp. radial; and 18 ABs 18-cylinder 635-hp. double-row radial. La Technique Aéronautique No. 144, 1937, pages 72–99, 56 illus.

Germany's New High-Power Motors. New DB 600 A/D Mercedes Benz is made in two versions, one supercharged to give maximum power (1000 hp.) at ground level, and the other to develop its maximum power (880 hp.) at 13,120 ft. It has a capacity of 33.9 liters. The Junkers Jumo 210 has one exhaust and two inlet valves, cylinders arranged in a 60° vee, and a capacity of 19.7 liters. Ground-boost model provides 680 hp. at 2700 r.p.m. and the supercharged version 640 hp. Few details. Aeroplane, August 18, 1937, page 201, 2 illus.

Hall-Scott Horizontal 180-Hp. Engine. Six-cylinder engine especially designed for use on motor coaches and developing 180 hp. at 2200 r.p.m. Drawings and brief description. Automotive Industries, September 18 1937, pages 397–398, 3 illus.

The Latest Tiger Engine. Armstrong-Siddeley Tiger VIII two-row 14-cylinder radial engine with a two-speed supercharger develops 805–845 b.hp. at 6250 ft. in its moderately supercharged form and the fully-supercharged type develops 725–760 b.hp. at 12,750 ft. Maximum power of the former is 860 b.hp. at 2450 r.p.m. at 6750 ft. Long description. Aircraft Engineering, September 1937, pages 247–248, 1 illus., 1 table.

Details of cylinders, dimensions, and weight of parts but no mention of performance. Aeroplane, August 18, 1937, page 210, 1 illus. Flight, August 19, 1937, pages 185–186, 1 illus. (Long description).

A New German Inverted Vee. Junkers inverted 60-degree vee twelve engine designed to run on 87-octane gasoline. Power at ground level is 680 b.hp. at 2700 r.p.m. A supercharged version develops 640 b.hp. at 15,000 ft, and is fitted with automatic boost control. Photograph and a few details. Flight, September 9, 1937, page 265, 1 illus.

Eight in Hand. Bloctube engine control unit fitted to the Handley-Page Harrow bomber provides throttle, mixture, D. H. propeller-pitch, air intake, and oil-cooler control for each of the two Bristol Pegasus engines. Photograph only. Flight, September 9, 1937, page 272, 1 illus.

Vibration Absorption in Engine Mounts and Instruments. Lord shear-type bonded rubber mountings for aircraft engines and instruments. Description. Aero Digest, September 1937, pages 64, 66, 6 illus.

Rocket Propulsion

Rockets Shortly Will be Used as Motors to Permit World Navigation. A. Ananoff. Experiments on rockets and on reaction propulsion for aircraft. Results obtained in the past in France, Austria, Italy, Czechoslovakia, and Russia. Les Ailes, September 9, 1937, page 9, 5 illus.

Meteorology

The Balloon that Talks by Itself. Telefunken "Radiosonde" sounding balloon recently developed in Germany is a combination of meteorological measuring instruments and a self-operating radio transmitter. It delivers the data during its ascent. Brief description. Flight, August 5, 1937, page 144a, 1 illus.

Aircraft Radio

Air Corps' Automatic Landing System. Capt. C. J. Crane and Capt. G. V. Holloman. Entirely automatic landing system. Short discussion. U.S. Air Services, September 1937, pages 21, 38, 1 illus.

Automatic Reel. Learadio light antenna reel. Few details of the automatic electrically-operated, and the manually-operated types. Aviation, September 1937, pages 58–59.

Fairchild Announces New DF. In the new RC-4 aircraft radio compass the loop is smaller and housed in a streamlined cover, and a new 15-tube receiver replaces the 8-tube receiver without increased weight. Few details. Western Flying, September 1937, page 42.

KHAH-Guba. D. G. Fink. Elaborate Bendix radio facilities provided for Richard Archbold's Consolidated PBY-1 flying boat "Guba." Equipment comprises five antennas, including two for direction finding, a main transmitter, an emergency transmitter, two receivers, both of which can serve for direction finding, d-f loop control facilities, and an interphone communication system. Such equipment was required because of the long Pacific hop to New Guinea and the necessity for contact between the ship and the field parties traveling on foot. Long description. Aviation, September 1937, pages 36–37, 2 illus.

The Modern Touch. How the technique of transport flying is changing with Swissair as an example. The radio equipment at Dubendorf and its traffic control arrangement are described. Flight, August 12, 1937, pages 169–170, 3 illus.

Safety in Flight in Germany. Entire issue of the magazine is devoted to this subject including the following articles: "Safety in Flight and Air Traffic," F. W. Petzel (Statics and map showing location of radio stations in Germany); "Central Transmitting Stations," F. Hentschel; "Ground Radio Stations," W. Robra; "Landing Beams," H. J. Zetzmann; "Overseas Radio Stations at Hamberg/Quickborn," H. Friedrich; "Central Radio Transmitting Stations," L. Benkert; "Lighting of Airports and Air Routes," F. Nickel; "Radio Apparatus on Board Transport Airplanes," R. Brueger; "Meterological Service," K. Bringmann; "New Weather Reception and Central Control"; "Apparatus for the Safety of Night Flights," (AEG lighting equipment advertisement). E.T.Z., August 19, 1937, pages 894–920, many illustrations.

Aero Radio Digest. Fairchild RC-4 aircraft radio direction finder Western Electric shielded loop antanna for aircraft, standard specifications for instrument-landing equipment, which were considered by the Bureau of Air Commerce, Aerovoice D-30 transmitter, Lear automatic reel, and Aeronautical Radio noise filter. Short descriptions. Aero Digest, September 1937, pages 92, 94, 7 illus.

Navigation with Loop Antennas. H. W. Roberts. The loop principle, classes of aircraft radio direction finders, prevailing method of indicating left and right, installation of an aircraft radio direction finder, calibration for corrections, precautions in using vertically polarized radiations, such as transmitted from broadcasting stations, for radio direction finding, directional radiators, cone of silence characteristics over TL type range beacons with loops mounted above and below, as observed by TWA, reciprocal bearings, and methods of plotting a line position. Aero Digest, September 1937, pages 72, 74, 4 illus.

Aeronautical Industry and Production

Aviation Gasoline to Japan. About 3,000,000 gallons of aviation gasoline will be dispatched to Japan from Los Angeles harbor within the next fortnight. Brief reference. Oil & Gas Jour., September 16, 1937, page 68.

Japanese Resources Bureau Prepares for War. Preparation for formation of a strict wartime economic structure started by the Resources Bureau of the Japanese Cabinet. Brief note. American Machinist, September 22, 1937, page 860d.

Pioneering in Mass Production. W. T. Piper. Methods used by the Taylor Aircraft Corporation in producing 25 Cub airplanes a week, and obstacles to low-price production. Aero Digest, September, 1937, pages 56–57, 62, 8 illus.

Procurement Planning of the United States Army Air Corps. Major J. L. Stromme. Necessity for procurement planning, examples of the waste in the World War due to bad planning, and an outline of the Air Corps plans. S.A.E. Preprint for Meeting, October 7–9, 1937, 7 pages.

War Plans for Sale. Production of military aircraft in the United States before, during, and after the World War, and photographs of military aircraft American factories are building for foreign trade. Western Flying, September, 1937, pages 18–21, 18 illus.

Welch's Interesting World Survey. Eleven countries estimated that they should produce some 23,598 commercial and military airplanes in 1937 but figures available for the first six months show only 6277 planes delivered. Figures given show the United States manufactured 1359 airplanes, U. S. S. R. 908, Great Britain 864, France 820, Germany 720, and Italy 700. Brief review of report. U.S. Air Services, September 1937, page 23.

Pilots

Physical Strain of the Crew in High-Speed Airplanes. H. von Diringshofen. Strains on the human body as a result of reduced air pressure, lack of oxygen, rapid changes of temperature, and engine exhaust gas are described by a doctor of the German Air Force. Effects on the crew of propeller noises, engine noises and vibration, straight-line and curved accelerations, and centrifugal forces are considered. Special physical strains imposed on the pilots of pursuit and diving airplanes, heavy bombers, and reconnaissance airplanes, respectively, and on sport fliers making long-distance, altitude, and acrobatic flights are also discussed. Luftwehr, September 1937, pages 359–366, 4 illus.

Air Forces

Short Spans. Argentina has purchased a large order of Fairchild radio compasses and aerial cameras, and Poland has placed an order for camera guns and Ranger engines. Brief reference. Western Flying, September, 1937, page 40.

Australia

Australia's Air Defence. It is understood that the Australian Defence Department intends to recommend increasing the R.A.A.F. to a strength of 17 squadrons, which means 204 first-line aircraft. Brief editorial on the squadrons required in case of attack by a hostile fleet. Flight, August 26, 1937, page 203.

Australia's Defences. "Danger to Australia of attack by Japan is greater than it ever was, and so we may assume that for something like adequate protection against Japanese invasion 500 fighting machines, including big bombers, would be nearer the figure for Australia's needs today than the mere 198 which are thought to be adequate." Editorial comment on the defense measures proposed by Australia's Minister of Defence. Aeroplane, September 15, 1937, page 307.

Australia's Revival. Australia's 1937–1938 budget presented to Parliament allocates £3,616,000 to the Navy, £3,264,000 to the Army, £2,672,000 to the Air Force, £1,039,000 to Munitions, and £940,000 to Civil Aviation. Brief note. Aeroplane, September 8, 1937, page 274.

China

PX'S. A total of 500 American-trained pilots are being enlisted for services in China according to reports in Los Angeles. Brief reference. Western Flying, September 1937, page 46.

Denmark

The Four Winds. Denmark's air force is shortly to acquire twelve Mercury-engined Fokker D.XXIs, ten of which will be built under license in the country. Brief reference. Flight, July 22, 1937, page 97.

France

Criticism of the Last Maneuvers. Commandant A. Langeron. Criticism of the recent air maneuvers in France. Les Ailes, September 9, 1937, page 11.

Tactical Phase of French Antiaircraft Artillery in the Operation of Large Troop Units. Abstract from "Instruction on the Tactical Use of Large Units," August 12, 1936. Luftwehr, September 1937, pages 374–378, 2 illus.

Germany

The Four Winds. Five hundred Messerschmitt 109 single-seater fighters will be in service with the German Air Force by November 1, according to reports. Brief reference. Flight, August 26, 1937, page 209.

PX'S. Germany is reported to be establishing a colony in Mexico in search of helium. Brief reference. Western Flying, September 1937, page 46.

Great Britain

A.A. Defence Under Fire. Britain's antiaircraft defenses, especially the new 3.7-in. guns, were criticized by Capt. G. K. Bourne in the Journal of the Royal Artillery. This editorial considers the criticisms and suggests that the R.A.F. fighters as well as bombers take part regularly and in considerable numbers in the antiaircraft training. Brief. Flight, July 29, 1937, pages 111–112.

The Coast Defence Exercises. Major F. A. deV. Robertson. Long detailed account describing how the British Army, Navy, and Air Forces worked together, the heavy bombardment of Portsmouth, and the "great black-out" when the whole of the Hampshire Coast and Isle of Wight were voluntarily darkened. Flight, July 22, 1937, pages 92–96, 5 illus.

Combined Coast Defence Exercise. Exercises to test the command and coordination of the naval, air, and land defenses of the fortresses of Portsmouth, Portland, and Plymouth, and to study the detailed handling of forces engaged in defense. Object of the exercises, and forces taking part. Flight, July 15, 1937, page 78.

Combined Operations in the North Sea. British flying-boat and General-Reconnaissance squadrons taking part in a Fleet Exercise in the North Sea, and a brief account of the Exercise. Aeroplane, September 15, 1937, page 313, 1 illus.

English Air Maneuvers. J. Arre. Account of the British 1937 Home Defense Air Exercises. U.S. Air Services, September, 1937, pages 17, 36.

Lights O'London. Visit to the 28th (Essex) Anti-Aircraft Battalion in camp and the work accomplished by the Anti-Aircraft Ground Defences. Flight, August 12, 1937, pages 156–158, 161, 10 illus.

The Air Defence Exercises 1937. C. M. McAlery. "In spite of their limitations the Air Exercises of 1937 have justified the confidence placed by the Air Staff in the aeroplane as a primary weapon in air defence . . . . although the bombers included some of the latest types introduced into the Service, they made a poor showing against the fighters, many of which were of inferior performance, but 'resolutely flown.' By day and by night, almost without exception, the bombers had to confess that they were intercepted by fighters." Long account of exercises. Aeroplane, August 18, 1937, pages 191–196, 14 illus.

Anti-Aircraft Shooting. A Queen Bee target airplane flying at about 4000 ft. and controlled by radio, was shot down in the Bristol Channel by an anti-aircraft Brigade of the Royal Artillery. The Queen Bee was about a mile away from the guns and was hit by the second volley just behind the motor. Its speed was about 100 m.p.h. and the visibility was not good. The target has only recently been taken into use by the Army. Brief reference. Aeroplane, August 18, 1937, page 183.

Us and Our Oil. Problem of insuring a Bristish oil supply in times of war with reference to the Mediterranean problem, submarine menace, underground storage, homegrown oil, and transformation of coal to oil. Aeroplane, August 18, 1937, pages 188–190.

A Promising Test. On the first evening of the British Air Exercises there were "fully thirty" raids of which at least half were intercepted, and all but two of the interceptions were made before the bombers had dropped their bombs. Ninety combats took place showing that most of the heavy bombers were intercepted more than once. During the exercises about 157 raids were made, of which about 127 were intercepted. Editorial on results. Flight, August 19, 1937, pages 177–178.

RUMANIA

The Four Winds. Rumania has ordered 24 Savoia Marchetti S.79 bombers capable of well over 250 m.p.h. Brief reference. Flight, July 29, 1937, page 119.

U. S. A.

The General Reports. Major General O. Westover. Fewer airplanes, but bigger ones are required by the development of modern air warfare. ". . . . these new airplanes are worth four or five times as much as the old-time types; they do four or five times as much military work. . . . . a well-rounded air force should have from 50 to 60 per cent bombers and as little as 40 per cent fighters." These are the answers General Westover gives to criticisms that the Army Air Corps is not now so well equipped as it was six years ago.

The process required in development of a new type of fighting airplane is described with praise for the work of the Material Division at Wright Field. Figures on the airplane strength and personnel of the Army Air Corps on June 30 are presented.

First half of the article is devoted to the General Headquarters Air Force and what it has been "up to" during the past year, reviewing its organization, functions, work, and personnel and airplane strength. Western Flying, September 1937, pages 15–17, 32, 7 illus.

The Flying Navy of 1938. Rear Admiral A. B. Cook. Air units and activities of the United States Naval aeronautical organization, aircraft program, appropriations for the fiscal years 1937 and 1938, delivery of new bombers capable of flying several thousand miles and carrying large loads of bombs, surface ships of the tender class to care for these flying boats, and the number of aircraft these ships can serve are discussed. Western Flying, September, 1937, pages 12–14, 6 illus.

Four Decades of Mechanization in the U. S. Army. Capt. R. J. Icks. Progress of automotive equipment in the U. S. Army during the period up to the World War. To be continued. Automotive Industries, September 25, 1937, pages 414–419, 432, 8 illus.

The Inevitable Parallel. H. C. Hartmann-Wrede. "Yes, the Air Corps does more than just fly! They are part of that combination which makes Uncle Sam No. 1 in aviation—and they not only fly the planes which defend the nation but help build them as well." Parallel between commercial and military aircraft development. U.S. Air Services, September, 1937, pages 16, 35.

Armament

Madsen Airplane Cannons. Airplane cannons of 20-mm. and 23-mm. caliber. Long description of construction and performance of these cannons produced by the Danish Madsen Workes with drawings of the design, and photographs showing the effect of the 23-mm. shell on linen and metal covering. Luftwehr, September 1937, pages 382–387, 5 illus.

The Oerlikon Cannon. In the Oerlikon automatic gun, being fitted to Continental military aircraft, the requisite support to the base of the shell is offered by the heavy mass of the bolt itself which is of the non-locking type. Facts and data are given, for the three Oerlikon models, the Hispano-Suiza engine cannon, and the FF gun for mounting within the wing. Mention is made of the gun designed for radial engines and of the models FFL and FFS intended for installation in larger and heavier aircraft and having muzzle velocities of 750 and 900 m./sec., respectively. A hit on a metal-covered wing by a 20-mm. shell from an Oerlikon gun and a gun intended for mounting in a wing are illustrated. Short article. Flight, July 22, 1937, page 100d, 2 illus.

L'Effet de Cazeaux. Firing trials of French multiplace combat airplanes at the proving ground for French aircraft armament proved that the deflection of bullets fired broadside detracted very seriously from the fighting value of the airplanes. Brief editorial on the problem and reference to data of the American Armament Corporation which has been endeavoring to develop and popularize aircraft guns of 37-mm. caliber. Flight, September 9, 1937, page 247.

Air Warfare

Aerial Warfare in Spain. Effectiveness of Russian, German, and Italian airplanes in the Spanish revolution. Translation from Revue de l'Armée de l'Air, February. U.S. Air Services, September, 1937, pages 25–26, 37.

Air War in China. Newspaper reports regarding the Japanese-Chinese situation and its probable effect on British trade. A second note, entitled "What Japan Knows," quotes remarks of Percy Noël in a Japanese newspaper concerning the Russian aviation industry. Aeroplane, September 15, 1937, pages 309–310.

Airplanes Versus Tanks. Lt. E. Mayer. Effectiveness of the tank as compared with the airplane in warfare. Firing from tanks, the tank *versus* artillery, damage to tanks, guns used in firing, armor, the tank as an easy target for the airplane, and antiaircraft firing. From Revue Militaire Suisse, May. Luftwehr, September, 1937, pages 369–371.

Aerial Ju-Jutsu. Cy Caldwell. " . . . by use of Air Power it is possible to effect paralysis of an entire country by exerting military pressure upon only a comparatively small part of it . . . by shutting off the supply of aluminum and steel from the Pittsburgh area, the air strategist is able to paralyze our entire West Coast airplane industry without dropping a bomb within 2000 miles of it." The vital strategic area of the United States is illustrated and the paralysis which would result from the bombing of just 18 generating plants in New York, of bridges on Trunk-line railroads, and of oil refineries are discussed. Aero Digest, September, 1937, pages 34, 39, 2 illus.